RADIOMETER

# The tc$pCO_2$ handbook

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## Introduction to transcutaneous monitoring


tc$pCO_2$/tc$pO_2$ monitoring ..... 6
TC methodology ..... 10
Combined measurements of tc$pCO_2$ $SpO_2$ ..... 12
General TC application advice ..... 20
Choice of measuring sites ..... 26
Choice of measuring temperature ..... 29


## Transcutaneous monitoring applications


Neonatology ..... 33
Pediatrics ..... 40
Operating room, ICU and step-down units ..... 45
Conscious sedation during diagnostic surgery ..... 50
Pulmonary/respiratory medicine laboratories or wards ..... 54
Sleep laboratories ..... 62
Veterinary hospitals/laboratories ..... 66


## Use of TCM4/40/TOSCA/CombiM monitors


Menu structure of TCM4/40/TOSCA/CombiM monitors ..... 70
Short-form support for:
*The TCM4/40/TOSCA/CombiM monitors* ..... 71
How to apply TC sensor ..... 78
Calibration ..... 81
Cleaning ..... 84
Maintenance of the sensor ..... 86
List of abbreviations ..... 93


## Complementary techniques


Choice of sensor site and temperature ..... 101

# Introduction to transcutaneous monitoring

The transcutaneous carbon dioxide and oxygen measuring techniques were first developed in the nineteen seventies. Since then, major further advances have been made and significantly improved the technology and practical application. Today, monitoring of transcutaneous gas tension is not only valuable for the respiratory and ventilatory status of neonates, but also highly relevant for the ventilatory care of children and adults with chronic respiratory failure. This development has followed the change in hospital care. Trends go in two directions: towards an increased application of non-invasive acute and long-term ventilation, and towards a more frequent use of techniques like high-frequency jet ventilation (HFJV), high-frequency oscillatory ventilation (HFOV) and other novel acute care therapeutic modalities. Together, these changes have led to an increased need for continuous focus on the patient's carbon dioxide ($CO_2$) status. Transcutaneous $CO_2$ monitoring meets these requirements non-invasively.



This handbook is primarily a guide to transcutaneous carbon dioxide (tc*p*$CO_2$) monitoring from a clinical perspective. However, as transcutaneous oxygen (tc*p*$O_2$) monitoring is sometimes relevant for the same patients (e.g. neonates on oxygen), the handbook also contains information on this parameter. For more in-depth information on tc*p*$O_2$ monitoring of patients with peripheral arterial disease (PAD), e.g. critical ischemia, please refer to "*The* tc*p*$O_2$ *handbook*". [*]

* Thomsen A, Wirth FV, Bryde-Jacobsen J. The tc*p*$O_2$ handbook.
Radiometer Medical ApS, Åkandevej 21, 2700 Brønshøj, Denmark, 2003.

As measurement of oxygen saturation by pulse oximetry ($SpO_2$) is often used in combination with tc$pCO_2$, and sometimes also tc$pO_2$ monitoring, this technique is described as well.

The handbook is based on scientific literature and the operator's manuals of Radiometer TCM monitors. According to the findings in clinical studies, the handbook provides suggestions on patient categories for which TC monitoring can be used.

References are found at the end of each section. For a more detailed presentation of technical issues and troubleshooting of transcutaneous monitors, please refer to the operator's manuals of these products.

Each section contains blank pages for the reader to make relevant notes and modifications according to local policies and procedures.



*Note:* The validity of any measurement must be carefully examined by a clinician/healthcare professional and related to the patient's clinical condition before any decisions are made on the basis of the measurement.

# tc$pCO_2$/tc$pO_2$ monitoring

## Continuous non-invasive monitoring

Patients with respiratory and cardiovascular disease, during anesthesia and surgery depend on having their carbon dioxide and oxygen status surveyed. Hypercapnia and hypoxia can result in acidosis requiring treatment; if undetected hypercapnia and hypoxia may lead to acidosic, hyperkalemia, myocardial depression, arrhytmias, arterial hypotension or hypertension, intercranial hypertension, narcosis and organ damage. Hypocapnia and hyperoxia may also have adverse and even severe damaging effects on the brain and other organs due to the vulnerability of cells and organs to changes in blood pH level and their dependence on oxygen. Continuous non-invasive transcutaneous monitoring of carbon dioxide and oxygen may be obtained in various ways and combinations:



- tc$pCO_2$
- tc$pO_2$
- $SpO_2$
- tc$pCO_2$ + tc$pO_2$
- tc$pCO_2$ + $SpO_2$
- tc$pCO_2$ + tc$pO_2$ + $SpO_2$

## Transcutaneous measurement of carbon dioxide and oxygen

Transcutaneous carbon dioxide and oxygen monitoring is a non-invasive way of continuously measuring the tension of these gases in the skin. A combined Clark-type and Severinghaus-type sensor also called Stow-Severinghaus sensor* is placed on the skin and heated. The sensor heat dilates the underlying capillaries and increases the gas diffusion through the lipid structure of the skin, thereby allowing carbon dioxide and oxygen to diffuse up to 20 times more quickly from the capillaries through the skin to the sensor. The oxygen generates a current and the carbon dioxide a potential in the sensor.

These signals are converted by the monitor and showed as tc$pCO_2$ and tc$pO_2$ values on the screen.



*In the literature the $pCO_2$ sensor is generally known as a Severinghaus-type sensor. However, Richard Stow originally invented the gas measuring technique and described it in 1954. Later that year, Leland C. Clark Jr. designed an arterial blood gas $pO_2$ sensor. In 1958 John W. Severinghaus developed a complete blood gas apparatus by combining his more practical version of Stow's $pCO_2$ sensor with Clark's $pO_2$ sensor. This is the reason why; the $pCO_2$ sensor is also known by the name Stow-Severinghaus sensor. Dietrich Lübbers, Albert and Renata Huch demonstrated together with Patrich Eberhard in 1972 that heating the skin to 42-45° C creates vasodilatation, which makes the cutaneous surface $pO_2$ value reasonable close to $PaO_2$, especially in newborn babies. After that were the transcutaneous $pCO_2$ sensor also developed and introduced to the market in the early 1980s [1].

## The sensor on the skin

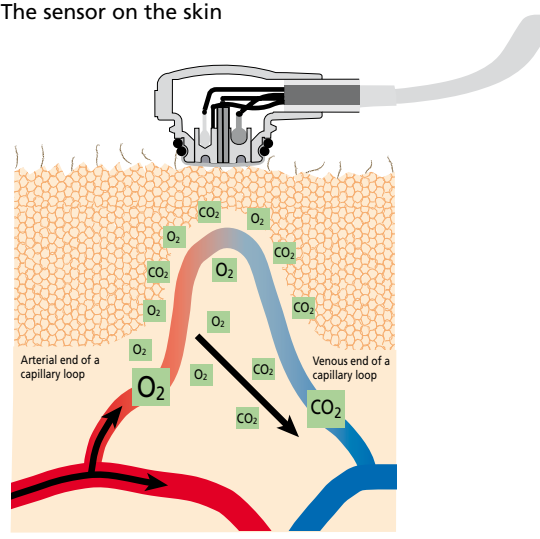




**FIG. 1: Transcutaneous $pCO_2/O_2$ monitoring (TC)**
The heat from the sensor dilates the capillary and increases local blood flow and the diffusion of $CO_2/O_2$ through the skin to the sensor. tc$pCO_2$/tc$pO_2$ is measured electrochemically inside the sensor.

### Are tc$pCO_2$/tc$pO_2$ identical to arterial blood gases?

It is a misconception that tc$pCO_2$/tc$pO_2$ are the same as arterial blood gases. The purpose of monitoring transcutaneous gas tensions is to obtain information on the cardio-respiratory condition of a patient without the need to repeatedly draw arterial blood samples for analysis. However, the transcutaneous partial pressure of oxygen reflects the underlying dermal $pO_2$ level that is influenced not only by the arterial $pO_2$ but depends on local blood flow, oxygen release from hemoglobin and skin metabolism. Living skin will always consume some oxygen and tc$pO_2$ will therefore always be lower than the arterial $pO_2$ irrespective of the sensor measuring temperature.
Similarly, dermal $pCO_2$ measured by a transcutaneous sen-

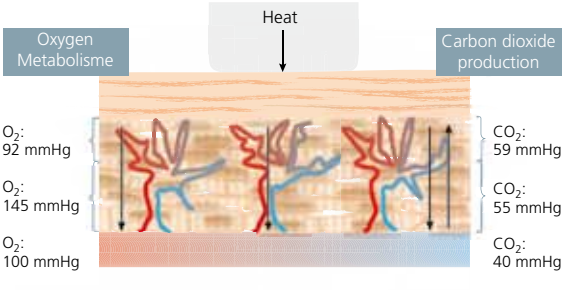


**FIG. 2: Example of the different levels of gases in blood to tissue**
Illustration of the physiological oxygen and carbon dioxide contents in a healthy subject's arterioles, capillaries and skin cells, when the heat from the TC sensor dilates the capillary and increases local blood flow. As part of the metabolic reaction there will be some oxygen consumption and an additional carbon dioxide production.

sor is not only determined by the arterial $PaCO_2$ but also influenced by local blood flow, and the skin metabolism. The cells metabolic´s $pCO_2$ addition is temperature-dependent, this influence is minimized by applying a temperature-specific constant and a metabolic factor; however, there will still be some difference between the tc$pCO_2$ value and the carbon dioxide tension in the arterial blood. Generally tc$pCO_2$ would be higher than $PaCO_2$ [2,3].



### tc$pCO_2$/tc$pO_2$ measures skin $pCO_2$/$pO_2$

tc$pCO_2$/tc$pO_2$ monitoring is an easy and non-invasive method that reflects the trends of changes of arterial blood gases. It provides assessment of the tissue's oxygenation and carbon dioxide removal via the cardio-pulmonary system. This information can indicate if an arterial puncture is required [4].

# TC Methodology

### Measurement of carbon dioxide tension

tc$pCO_2$ measurement is in fact a pH measurement. $pCO_2$ from the skin diffuses through the membrane of the sensor into an electrolyte solution. Here it reacts with water, forming carbonic acid that immediately dissociates into $HCO^{3-}$ and $H^+$ according to the following equation:

$$H_2O + CO_2 \leftrightarrows H_2CO_3 \leftrightarrows H^+ + HCO^{3-}$$

As $HCO^{3-}$ in the electrolyte solution is kept at a fixed level, changes in the $H^+$ concentration will always be equivalent to changes in pH. These pH changes alter the voltage between the glass sensor and the reference sensor. The measured pH is converted into a carbon dioxide reading by the Henderson-Hasselbalch equation and is shown as a tc$pCO_2$ value in either mmHg or kPa [5,6]



### Oxygen measurement

Oxygen from the skin passes through the sensor membrane. It reaches the cathode, which consists of platinum. Here oxygen is reduced as a result of the current-generating process:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

The silver ring surrounding the platinum cathode is the anode where the following oxidation reaction takes place:

$$4Ag + 4CL^- \rightarrow 4AgCl + 4e^-$$

The reduction of oxygen generates a current that is converted by the monitor into a voltage and a digitized tc$pO_2$ value in mmHg or kPa [5,6].

Notes




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## Combined measurements of tc$pCO_2$ and $SpO_2$

### Combined tc$pCO_2$ and $SpO_2$ sensor

Pulse oximetry provides instant and continuous information about oxygen saturation and pulse rate. It does not, however, indicate how much hemoglobin is available in the blood. Oxygen saturation measurement is often used together with tc$pCO_2$ as they compliment each other and provide a wider perspective of the patient's blood gas status. Pulse oximetry is widely accepted because of its non-invasive character, ease of use and low cost. It is also considered easy to interpret; however, the technique has certain limitations that are important to keep in mind in order to obtain optimum patient monitoring.

### $SpO_2$ methodology



A pulse oximeter sensor typically contains two light-emitting diodes (LEDs) – one with red light and one with infrared light. The light passes through a blood-perfused tissue to a photodetector on the other side of the finger, earlobe, foot or toe or is reflected by bone and other structures. The more light-absorbing blood that is present at the moment of measurement, the less light reaches the photodetector [7].

The illustration next page shows a spectrophotometric measurement of blood with an overlap of the red (660 nm) and infrared (900 nm) light. The two absorption peaks represent oxygenated ($O_2$Hb) and deoxygenated (HHb) hemoglobin.

Because $O_2$Hb absorbs less red light than infrared light, the underlying blood flow at high saturation values has less influence on the detected red signal than on the infrared one. At

low saturation values this situation is reversed and far more red than infrared light is absorbed. Thus, the arterial oxygen saturation can be derived from the ratio of the red and infrared light absorption. $SpO_2$ measurements indicate how much oxygen is actually bound to the available hemoglobin in the blood, but it does not show the hemoglobin or dyshemoglobin concentration. Therefore $SpO_2$ might not always show the actual blood oxygen status [8].

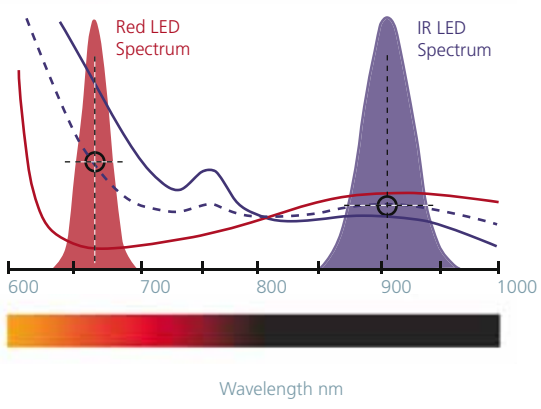


**FIG. 3: LED-emitted light spectrum**
Overlapping of typical LED-emitted light spectra and relative light absorption spectra of oxygenated and deoxygenated hemoglobin. The dashed purple line indicates the spectrum of 50 % saturated blood, with the relative absorbance in the red and infrared indicated by the black circles. Figure and text is reprinted by permission of Nellcor Puritan Bennett Inc. Pleasanton, California [8].

### The relation between $SpO_2$ and $pO_2$

The oxygen dissociation curve describes the relationship between oxygen tension ($pO_2$) and oxygen saturation ($SpO_2$) at standard conditions (Fig. 4).

This relationship can be used with some restriction to estimate $pO_2$ from $SpO_2$. The position of the dissociation curve is, however, shifted either to the left or the right by changes in pH, temperature, 2,3-DPG, $pCO_2$ level, and the presence of dyshemoglobins.

A multicenter study of these variables resulted in the curves shown in (Fig. 5). When oxygen saturation is read from this curve with a $PaO_2$ of 8 kPa (60 mmHg), the corresponding $SpO_2$ value ranges from 69.7 % to 99.4 %. At $SpO_2$ level of 90 %, the $PaO_2$ values ranges were 3.82 and 18.3 kPa (29 and 137 mmHg). Beside this inaccuracy in some patients, it is also important to realize that, $SpO_2$ cannot differentiate between hypoxemia caused by ventilation/perfusion mismatch and that caused by alveolar hypoventilation. These examples illustrate that oxygen saturation does not always provide a precise estimate of hypo- and hyperoxia. In terms of oxygen transport, however, the oxygen saturation technique together with the hemoglobin measurements is quite important [9,10].

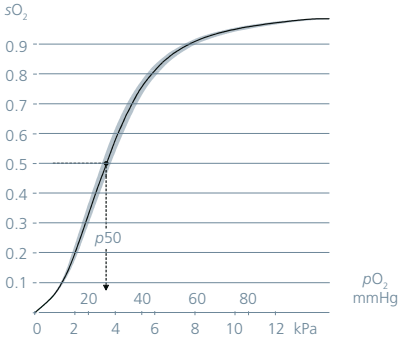


**FIG. 4: Oxygen tension vs. saturation**
The Oxygen Dissociation Curve. $p_{50}$ is defined as the oxygen tension of half saturation, $sO_2$ = 50 %

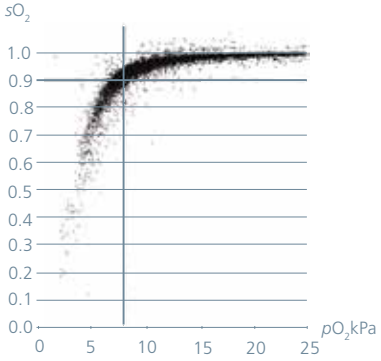


**FIG. 5: Oxygen tension vs. saturation**
The curve from a multicenter study shows the measured oxygen tension vs. the saturation in 10,079 arterial blood samples [9].

### $SpO_2$ bias due to motion, level of skin pigmentation

Motion artifact is often a problem for pulse oximetry and may result in false readings or alarms. A study that compared finger saturation probes and the number of false alarms showed significantly fewer false alarms on the middle finger compared with measurements on the index finger, which is most often used as measuring site.

$SpO_2$ measurements may also exhibit erroneous readings due to high patient skin pigmentation or nail polish. Some sensors may even show a small bias when measuring on women. Furthermore, correct sensor fixation is very important to ensure optimum light-tissue interaction and thereby reliable measurements [11,12,].

### Earlobe sensors vs. finger $SpO_2$ sensors



A study showed that a combined earlobe tc*p*$CO_2$/$SpO_2$ sensor detects changes in oxygen saturation significantly earlier than a finger $SpO_2$ sensor. This can be explained by a difference in the lung-to-ear vs. lung-to-finger circulation time and by differences in the vascularization of the monitored tissue. The signal processing technique, and the use of a heated sensor affect the response time of pulse oximetry as well. Other studies have shown that the earlobe is less affected by systemic vasoconstriction, which also makes the earlobe a good site for transcutaneous carbon dioxide measurement [13,14,15,16,17].

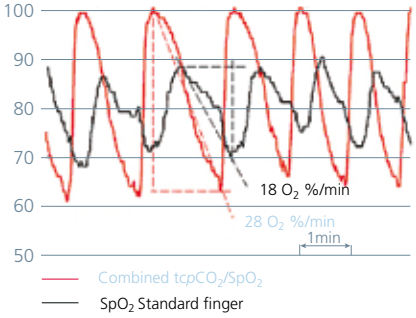


**FIG. 6: $SpO_2$ response time**
The response time of a heated combined tc$pCO_2$/$SpO_2$ earlobe sensor is faster than that of an unheated finger probe. As a result, the detection of the beginning and end of the desaturation happens 20-30 seconds earlier by the earlobe sensor and the obtained amplitude is nearly two times greater, indicating a larger specificity. This is important for patients with rapid and transient changes in $SpO_2$ for example sleep apnea. As not only the number of desaturation events but also the degree of these events correlate with the impairment of the cognitive function and with cardiovascular complications. A short response time is essential in order to detect fast changes of the oxygen saturation [15].

## The combined tc*p*$CO_2$/$SpO_2$ sensor

The combined tc*p*$CO_2$/$SpO_2$ sensor pictured below gives fast information of these parameters together with the pulse rate.

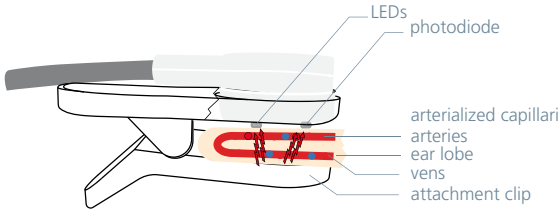


**FIG. 7: The tc*p*$CO_2$/$SpO_2$ sensor**
tc*p*$CO_2$/$SpO_2$ is measured by an earlobe sensor attached by a clip. The technique is a combination of the above shown TC technique and a spectrophotometric pulse oximetry measurment. This TC sensor contains a gold shield that protects the membrane, thereby allowing the sensor to provide reliable measurements for up to 14 days without membrane change. Recommended measuring temperature: 42 °C (108 °F).



$SpO_2$ is widely accepted due to the non-invasive character of the method, its ease of use and low costs – and when the limitations of the oxygen saturation technique are taken into consideration, the results are easy to interpret. $SpO_2$ measurement in combination with tc*p*$CO_2$ provides a continuous estimation of the patient's arterial oxygen saturation and of pulse rate together with information on the carbon dioxide tension in the skin and thereby the body´s ability to oxygen uptake and to eliminate carbon dioxide via the cardiopulmonay system. All together this provides valuable information of the patient's cardio-respiratory status as an adjunct to decision making on the patient's care.

Notes


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## General TC application advice

### Practical application

An ideal TC measuring site is an area of skin over a homogeneous capillary bed with no large veins, skin defects or hair. Placing the sensor directly on top of a bone or a scar may cause erroneous results because of locally impaired perfusion of these sites. Severe edema may also lead to unreliable results because of the reduction of blood flow caused by a compression of the capillary loops and a longer diffusion pathway. For more information, refer to the section on measuring sites on page 26.

### The sensor

The sensor must be in contact with the skin through the contact liquid or gel. This is to avoid bias from atmospheric air between tissue and sensor. If there are air bubbles, they will affect the measurement, resulting in too high oxygen and too low carbon dioxide levels. For more information, refer to the section on how to apply the TC sensor on page 78.



### Initiation of TC monitoring involves sensor stabilization time

It takes about 3-7 minutes after the sensor has been placed on the skin for the tc$pCO_2$ values to stabilize and it may take a further 10-17 minutes to obtain reliable tc$pO_2$ values. Preheating the skin may reduce this time to 3-6 and 5-16 minutes, respectively. tc$pCO_2$/tc$pO_2$ is considered stable when TC values during stable patient conditions do not change more than about ± 2 mmHg (±0.25 kPa) within 1 minute.

### tc$pCO_2$ lag and response time

A study in healthy subjects evaluated tc$pCO_2$ lag time and defined it as: "The time from the initiation of an intervention of the gas status to the initial response of the sensor". The mean lag time for tc$pCO_2$ during hypercapnia was 16.8 ± 1.3 seconds. When the subjects resumed breathing room air from hypercapnia, the mean lag time was 14.2 ± 1.4 seconds.

The response time may be defined as: The initiation of an intervention in the gas status to the maximum (100 %) response of the sensor. The 90 % response time was 77.9 ± 6.7 seconds. tc$pCO_2$ has a shorter response time compared with tc$pO_2$. This is most likely due to a hypercapnia-induced increased cardiac output, capillary perfusion and faster carbon dioxide diffusion through the epidermis [18].



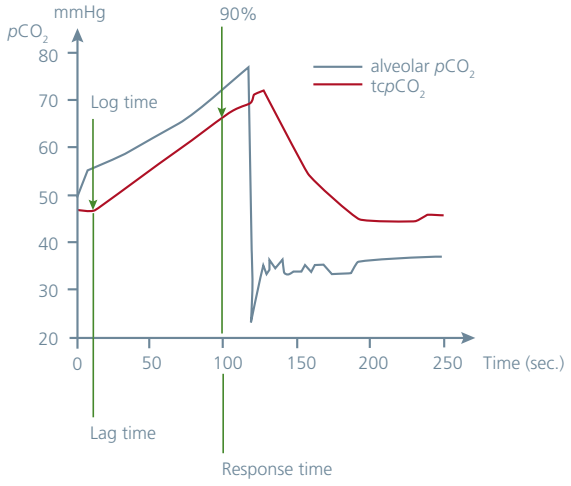
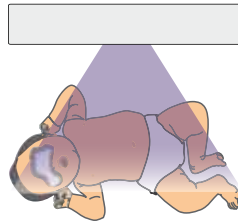



**FIG. 8: The tc$pCO_2$ response and lag time**

### UV light

Measurements of tc$pCO_2$ and $SpO_2$ may be affected by bright light from an UV lamp, e.g. used for jaundiced neonates undergoing light therapy. Some sensors are better shielded from UV light than others; however, additional shielding is still recommended [19].



### MRI-scanning

To minimize the risk of an electromagnetic field interfering with the TC measurements, the TC monitor must always be placed in a safe distance to the MRI-scanner. For TC measurements during MRI-scanning the relevant length for the sensor extension cable can be calculated with support from the TCM operator's manual.



### Vasoconstriction

There is some disagreement about the reliability of tc$pCO_2$/tc$pO_2$ in cases of epidermal vasoconstriction caused by vasoconstricting agents, toxins in sepsis patients, hypothermia or elevated cutaneous vascular resistance as seen in patients with hypovolemic or cardiogenic hypotension and low cardiac output. Several studies have documented that vasoactive substances like dopamine, tolazoline, isoproterenol, nitroprusside, aminophylline, hydralazine, epinephrine, dobutamine, phenylephrine and norepinephrine did not affect tc$pCO_2$/tc$pO_2$ measurements [20,21,22, 23].

In a coexisting study, that confirms that the above-mentioned catecholamines did not affect TC measurements, the authors conclude: "However, in cases with profound skin vasoconstriction or shock the correlation between tc$pCO_2$ and $PaCO_2$ is low*". In these situations low tc$pO_2$ may be the first warning of a developing hypotensive shock [22,24*,25].

Smoking and chewing nicotine gum have been observed to decrease the tc$pO_2$ value for up to 50 minutes, while tc$pCO_2$ remained unaffected [26].

### Skin temperature

A relatively large tc$pCO_2$ to $PaCO_2$ bias has been observed under hypothermic conditions, defined as patients with a rectal temperature lower than 36 °C (97 °F) [24].

### Body mass index

Some studies suspect that skin thickness in severely obese adults affect the permeability for carbon dioxide diffusion and the vasodilatation of the underlying capillaries from the heating element in the TC sensor. However, several studies have confirmed that tc$pCO_2$ is not influenced by body mass index; on the contrary, tc$pCO_2$ has been reported to be the same in both obese and lean individuals [21,22,27].



### Pigmentation

tc$pCO_2$/tc$pO_2$ measurement is based on an electrochemical measurement of carbon dioxide and oxygen diffusing through the skin. As the TC technique does not use light, as used in $SpO_2$ measurements, it can be used for patients of all races without any bias caused by different levels of skin pigmentation [21].

### Age influences the respiration

The aging process is associated with an increased risk of hypercapnic respiratory failure in patients with pneumonia, congestive heart failure or exacerbation of chronic obstructive pulmonary disease (COPD). The increased $PaCO_2$ may be related to the age-related decrease in both respiratory muscle strength and compliance of the respiratory system, as well as to a lower response of the respiratory center etc. A $tcpCO_2$ study on respiratory patients aged 66-97 years has shown a high correlation with $PaCO_2$ and a low bias. The authors write, "the limit of agreement was compatible with clinical use (8.3-8.5 mmHg/1.1 kPa)". Furthermore, the heat (43°C (109 °F) from the sensor was shown to be well tolerated by older patients, even after recordings at the same measuring site for up to 8 hours [27].

### Neonatal TC correction factor

Some doctors recommend that the metabolic correction factor on the TC monitor is changed from the standard –4 or –5 mmHg (–0.5 or –0.65 kPa) to –8 or –10 mmHg (–1 or –1.3 kPa) for neonatal measurements. This is due to the infant skin structure. The difference in skin structure is also the reason why transcutaneous carbon dioxide and especially transcutaneous oxygen have a much higher $PaCO_2/O_2$ correlation in neonates than in adults.



### The operational conditions

It is recommended to have standard conditions in order to get reliable results:

- Ambient temperature of 5-40 °C (41-104 °F)
- Relative humidity of 20-80 %.

Notes

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## Choice of measuring sites

### Optimum measuring sites

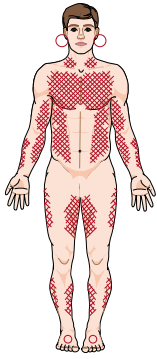
Optimum transcutaneous measuring sites are areas with good skin perfusion. Generally, the best reflection of central arterial $pCO_2/pO_2$ is obtained with a chest position of the sensor and with high temperature settings (max. 44 - 45 °C).

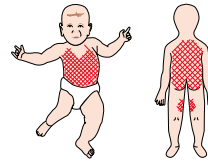
### Preparing the measuring site

The selected site should be without large veins, skin defects, hair or fat from oil, cream or fetal fat. If necessary, shave and wash the site with alcohol. Placing the sensor directly over a bone may cause erroneous results. Severe edema will also result in unreliable results.

Do not place the sensor directly on previous operation sites, e.g. on patients who have had heart, lung or breast surgery. Local perfusion at these sites is lower due to scar tissue. It is not recommended to use TC sensors on patients with severe dermatological problems such as seen in areas of skin damage due to Prednisolone treatment, burns or allergic reactions etc.







tc$pCO_2$ and tc$pO_2$ measuring sites

- Earlobe (Single tc$pCO_2$ or combined tc$pCO_2$/$SpO_2$ sensor)
- Face (*)
- Laterally on the neck (seldom used)
- Chest, in the intercostal space (provides the best reflection of $PaO_2$/$PaCO_2$)
- Lateral abdomen on skinny adults or on children and neonates
- Back (mostly on neonates)
- Ventral side of the upper arm and forearm
- Seat (mostly on neonates or for ischemia patients)
- Thigh (for tc$pO_2$ measurements on babies or PAOD patients)
- Legs (only for diagnosis of PAD/ischemia)

### Change measuring sites

Because the sensor is heated this may cause local hyperemia of the skin, which may disappear within 5-15 minutes. However, on patients with delicate skin this local hyperemia may last for up to 24 hours or longer. If the sensor is left on the same site too long there is a risk of burns. Therefore, it is necessary to change measuring site regularly. For more information, refer to the section on choice of measuring temperature on page 29.



### TC monitoring on neonates and children

Neonates and small children have very thin skin that allows measuring on the back and on the bottom with good results. At the same time they are more vulnerable to the heat from the sensor. Therefore it is important to either lower the measuring temperature or to change sensor site more frequently, especially when measuring on very preterm infants. This may be done

(* Some doctors do not want to use this site because of the risk of skin reactions)

by attaching two or three fixation rings to the infant and then change sensor position between these rings. Remember to dry the fixation - well and refill it again before use. Altogether this will disturb the infants as little as possible. The fixation rings should however, be removed from the skin every 12-24 hours, depending on the condition of the skin [19].

### Avoid direct pressure on the sensor

Direct pressure should never be placed on the sensor while it is on the patient, and the patient should never lie on the sensor. Direct pressure may cause invalid measurements and/or cause skin necrosis.

*Notes*



19. Myers CS. Measured results: pulse oximetry is proving the simple solution to many COPD disease management programs' success. The Journal for Respiratory Care Practitioners 1996; Aug./Sep.: RT 83-86.

## Choice of measuring temperature

### Optimum transcutaneous measuring temperature

The optimum transcutaneous measuring temperature is 42-45 °C (108-113 °F). However, measuring time and skin diffusion conditions are important when choosing the temperature.

- The best reflection of central arterial $pO_2/pCO_2$ is obtained with a high sensor temperature, i.e. 44 °C (111 °F)
- The higher the temperature, the shorter the response time
- Skin diffusion depends on the patient. The thin skin of neonates and children makes it possible to obtain reliable measurements at lower temperatures than on adults

(tc$pCO_2$/tc$pO_2$ values can be obtained at low temperatures like 37-38.5 °C (99-101 °F) but the measured values do not reliably reflect arterial blood gases and these low measuring temperatures are therefore only used in special pharmaceutical research settings.)



### Reducing risks of skin reactions

To reduce the risk of burns it is necessary to change the measuring site regularly and/or use a lower sensor temperature. A good correlation of the measurement can still be obtained by choosing a high initial temperature of 43-45 °C (109-113 °F) for the first 5 minutes; a feature that is automatic in some monitors. This will increase the dilatation of the underlying capillaries and the gas diffusing through the lipid structure in the skin. This will be the case also after the temperature automatically has been lowered again when using a smart heat function [3].

Patients with the following clinical conditions have higher risk of getting burns from the electrode:

- Shock
- Very low blood pressure
- Distinct systemic vasoconstriction
- Very sensitive skin

### Neonates and children

On neonatal and children's wards it is common to choose a tc$pCO_2$/tc$pO_2$ sensor temperature of 42.5-43 °C (108-109 °F) for 2-4 hours, or 44 °C (111 °F) for a maximum of 2 hours. For very preterm neonates a temperature as low as 42 °C (108 °F) may be the optimum choice [28,29].

Transcutaneous carbon dioxide in neonates has been shown to have a close correlation with $PaCO_2$ at a sensor temperature of 40-44 °C (100-111 °F). However, transcutaneous oxygen is best measured at a higher sensor temperature of 42-44 °C (108-111 °F) [27].

A switch on Smart Heat function, which increases the temperature by 1 °C (1.8 °F) for the first five minutes of measuring, can only be recommended for infants with a weight above 1,000 g. [28].



*Note:* The physiological stabilization time of the sensor is 15-20 minutes for the tc$pO_2$ reading and 3-7 minutes for the tc$pCO_2$ reading. During this time the sensor will slowly heat the skin, making the arteries dilate. Longer stabilization time may indicate a need for changing the membrane of the sensor. Other reasons could be an incorrect attachment of the sensor, a poorly selected measuring site or an old sensor.

### Adults

On adults the optimum tc$pCO_2$/tc$pO_2$ temperature and measuring time is 44-45 °C (111-113 °F) for up to 4 hours. However, when there is a need for longer measuring periods of tc$pCO_2$ only, the literature often refers to temperatures around 43 °C (109 °F), depending on patient skin condition. Many sleep laboratories use temperature settings of 42-43 °C (108-109 °F) [30].

A study has shown that a sensor temperature of 43 °C (109 °F) was well tolerated for 5-8 hours of continuous monitoring [30].

**Single tc$pCO_2$/combined tc$pCO_2$/$SpO_2$ earlobe sensor**

Please note that with a single tc$pCO_2$ or combined tc$pCO_2$/$SpO_2$ earlobe sensor it is possible to obtain reliable adult carbon dioxide estimation at 42 °C (108 °F) for more than 8 hours without changing measuring sites or calibrating the sensor [21].

*Notes*

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# Transcutaneous monitoring applications

## A wide range of patients

Transcutaneous monitoring can be used in a number of different patient segments. Historically, the technique has grown from a reliable and beneficial tool for monitoring the carbon dioxide and oxygen situation of neonates to a method that is applicable for many cardiovascular and respiratory patients of all ages. Apart from wound care and hyperbaric medicine, where the main focus is on local tc$pO_2$ measurement, a growing number of physicians have become aware of the benefit of reliable tc$pCO_2$ measurements.

In this part of the handbook the use of tc$pCO_2$ monitoring (and to some extent tc$pO_2$) in the following clinical setting applications is described:



- Neonatology
- Pediatrics
- Operating room, ICU and step-down units
- Pulmonary/respiratory medicine laboratory or wards
- Sleep laboratories
- Veterinary hospitals/laboratories

## Neonatology

### Why it is essential to monitor arterial $pCO_2/pO_2$

Continuous monitoring of both carbon dioxide and oxygen is essential in ill neonates. Changes may occur fast. With intermittent monitoring or repeated blood gas analysis, these changes can go undetected, and may eventually result in organ damage [28].

### Decreased arterial carbon dioxide

Decreasing $PaCO_2$ results in decreased cerebral blood flow and several studies on neonates have demonstrated a strong correlation between low $PaCO_2$ and adverse cerebral outcome. At values of 22.5 mmHg (3.0 kPa) or less, damage can occur within a few minutes, but also exposure to slightly higher partial pressures (mmHg) for a longer period of time may be dangerous. Therefore, it is important to monitor carbon dioxide levels [28,31,32,33].



### Reducing the number of blood samples

Analysis of arterial blood samples provides accurate estimates of blood gases. However, they provide a momentary picture of the status only. Repeated sampling may not only disturb and stress the neonate, it may also cause the need for a blood transfusion. A significant change in cerebral circulation and thereby oxygenation is documented in relation to sampling from umbilical artery catheters. The number of blood samples should therefore be reduced to an absolute minimum and be combined with transcutaneous monitoring of carbon dioxide and oxygen. The TC technique provides continuous information on the neonate's ability to supply oxygen to the tissue and remove carbon dioxide in the tissue via the cardiopulmonary system. The TC technique follows the trend and changes of these gases [28,34].

### Hypocapnia and lung damage

Hyperventilation results in hypocapnia. Low $pCO_2$ before surfactant treatment as well as during ventilation treatment has shown to correlate with the development of chronic lung disease in the preterm infant. In the ventilated preterm infant, it is therefore recommended to monitor $pCO_2$ continuously to minimize the risk of lung damage [28,35].

### Ventilation

Ventilation may cause a pneumothorax, and an early diagnosis is likely to improve patient outcome. Unfortunately, this diagnosis is often made rather late. A study showed that the median time from onset to clinical diagnosis was 127 minutes. An elevated $tcpCO_2$ without any change in oxygenation may be an indicator of this condition. As $tcpCO_2$/$tcpO_2$ continually follows the changes in carbon dioxide and oxygen tension with only a short delay, faster intervention is made possible [28,36]



### $tcpCO_2$ vs. end-tidal $pCO_2$

A study that compared end-tidal $pCO_2$, $PaCO_2$ and $tcpCO_2$ showed that the difference between end-tidal $pCO_2$ and $PaCO_2$ significantly increased during one-lung ventilation, as one lung ventilation impairs ventilation/perfusion matching. The study showed that $tcpCO_2$ reflected $PaCO_2$ better than end-tidal $pCO_2$ [37]. In infants with cardiopulmonary disease, end-tidal $pCO_2$ has been shown to have a poor correlation with arterial values and should therefore not be used. These patients are, according to several studies, more effectively monitored by $tcpCO_2$ [37,38,39].

*Note:* In patients with Patent Ductus Arteriosus and right-to-left shunt, tc$pO_2$ will be higher on the upper part of the thorax than on the lower part. In these patients the sensor should be placed on the lower back or abdomen or on the thigh. Futhermore, arterial blood samples for validation should always be drawn from the same side of the shunt as the tc$pCO_2$ value is being measured [40,41].

### High Frequency Oscillatory Ventilation (HFOV)

Since only the proximal airway pressure is monitored during high-frequency oscillatory ventilation (HFOV), no alarm will occur if there are either an obstruction or restriction of the airway. The technique also induces a risk of hyperventilation resulting in hypocapnia. Therefore many manufacturers of HFOV recommend continuous measurements of tc$pCO_2$/tc$pO_2$ and $SpO_2$ during this form of treatment. This is particularly important in larger children, who have more dead space and a greater metabolic demand when on ventilation [42].



### Hyperoxia in infants

In newborn preterm infants hyperoxia reduces cerebral blood flow for hours after oxygen status has normalized. At the same time hyperoxia has a toxic effect on the lungs and may possibly cause retinopathy in preterm infants. Monitoring tc$pO_2$ provides a method of early detection of hyperoxia, which may not be detected by transcutaneous $SpO_2$ measurement [28,43,29].

## Clinical guidelines on TC measurements

The relevance of transcutaneous monitoring is substantiated by the American Association for Respiratory Care (AARC) guidelines and the National Clearinghouse Guidelines (US).



### AARC guidelines and National Clearinghouse Guideline (US)

According to the AARC practice guidelines, transcutaneous blood gas monitoring of neonatal and pediatric patients should be used if there is a:

- need to monitor the adequacy of arterial oxygenation and/or ventilation

*and/or*

- need to quantitate the response to diagnostic and therapeutic interventions as evidenced by tc$pCO_2$ and tc$pO_2$ values

The guidelines point out that tc$pCO_2$/tc$pO_2$ is appropriate for continuous and prolonged monitoring, e.g. during mechanical ventilation, continuous positive airway pressure (C-PAP) and supplemental oxygen administration. Furthermore, tc$pO_2$ can be used for diagnostic purposes as in the assessment of functional shunts, e.g. in neonates with persistent pulmonary hypertension or persistent fetal circulation, or to determine the response to oxygen challenge in the assessment of congenital heart disease [41, 44].

Please note that during ventilation studies the sensor site and an arterial sampling site in patients with functional shunts should be on the same side of the shunt [41,44].

Transcutaneous blood gas monitoring should be applied continuously to develop trending data. So-called spot checks (intermittent short measuring periods) are not appropriate [41,44].



## Conclusion

To sum up, transcutaneous carbon dioxide and oxygen tension monitoring should be applied in neonates whenever there is a risk of sudden changes in carbon dioxide or oxygen status, for example in the following conditions:

- Asphyxia, germinal layer hemorrhage, meningitis or head trauma
- Respiratory Distress Syndrome (RDS)
- Persistent pulmonary hypertension or pneumothorax
- During surfactant treatment
- During treatment with various forms of assisted ventilation (positive pressure ventilation such as CPAP, Bi-PAP; HFOV)
- During weaning from ventilator or change in ventilation strategy
- After extubation



*Notes*

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## Pediatrics

### Transcutaneous $pCO_2$/$pO_2$ monitoring in children

Transcutaneous monitoring of carbon dioxide and oxygen tension has shown to be clinically relevant in respiratory ill newborns as well as in children in all ages [45,46,47].

The cerebrovascular carbon dioxide reactivity in young children is comparable to that of the newborn, and the risk of hypo-capnia-induced cerebral ischemia in children is similar to that in neonates. Because of this, continuous monitoring of carbon dioxide tension is necessary in both patient groups [28,48].

### Respiratory Syncytial and other Virus infections

Among small children, Respiratory Syncytial Virus infections pose a risk of serious respiration insufficiency, and it is the most frequent cause of hospitalization in many countries [49,50].



Many children are uncomfortable or even afraid of the staff and equipment in hospital. It is well known that this fear can persist for a long time after leaving hospital. Therefore in children's wards it is even more important to minimize the invasive surveillance, and transcutaneous monitoring of carbon dioxide and oxygen tension trends allows non-invasive respiratory surveillance.

### Respiratory support

Transcutaneous blood gas monitoring is an important adjunct to detect the need for and to guide assisted ventilation. In addition, it helps to detect complications such as obstruction either in the ventilation equipment or in the upper airways.

### Obstructive sleep apnea and other sleep related breathing disorders

During polysomnography for evaluation of pediatric obstructive sleep apnea (OSA) and sleep related hypoventilation, tc$pCO_2$ as well as end-tidal $pCO_2$ can been used. Several studies have shown that gas exchange is efficiently monitored with tc$pO_2$/tc$pCO_2$ in children with COPD during sleep. tc$pCO_2$ is particularly useful for children who do not tolerate a nasal sampling tube and for those with moderate to severe partial airway obstruction, tachypnea or increased physiological dead space, where end-tidal $pCO_2$ underestimates the arterial $pCO_2$ level. tc$pCO_2$ has been shown to provide an accurate estimation of $PaCO_2$ over a wide range of carbon dioxide values in young and older pediatric patients with respiratory failure [23,51,52,53].

### Asthma

WHO estimates that 300 million people (children and adults) suffer from asthma and 2.550.000 people died of asthma in 2005. Asthma is the most common chronic disease among children and the numbers are increasing. One example: From 1980 to 1994 the prevalence of asthma in the US increased more than 160 % in children under 5 years of age, and a total of more than 9 million US children under 18 have been diagnosed with the disease (1998). In these patients a challenge test of the lung function may be necessary [54,55].

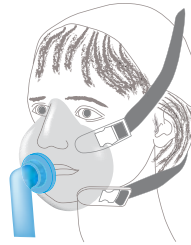


## Lung function measurements

A 20 % fall in tc$pO_2$ can be used as the only indicator for a bronchial reaction during a histamine bronchial provocation test in awake, young children. Ventilation changes evaluated by tc$pCO_2$ measurements makes it possible to distinguish between a fall in oxygen tension due to an early, "false" reaction as a result of hypoventilation, and a "true" bronchial reaction. [56].

A study on lung function measurements in awake 2 to 6 year old children has documented that lung function can be assessed by transcutaneous measurements, forced oscillation technique (Rrs5*), whole-body plethysmography (sRaw*) respiratory reactance (Xrs5) and interrupter technique (Rint*). All these techniques provide reliable tools for monitoring the response during bronchial challenge test with pharmacological agents. The reproducibility of the measurements and the sensitivity in detecting changes in the airway function are good and favorable, compared with standard techniques like the forced expiratory maneuver ($FEV_1$*) in small children. Small children do not have the ability to perfome the $FEV_1$ manoeuvre correctly [57,58].





(*Rrs5 = Respiratory resistance (measured by oscillation technique).
Rint = the interrupter technique for measuring respiratory resistance.
sRaw = Whole-body plethysmography for measuring the specific airway resistance.
$FEV_1$ = forced expiratory volume in 1 second, FEV1% vital capacity (VC).
*Xrs5 = respiratory reactance (measured by oscillation technique) (Methacolin was used as pharmacological test agent) [57,58].

### Exercise testing

Hemodynamic studies during heart catheterization in children are usually performed at rest. This could result in exercise-induced right-to-left shunts being missed. tc$pO_2$ monitoring during exercise testing is a non-invasive means of detecting these shunts [59].

### More indications for TC monitoring

Please refer to the neonatal part of this handbook, as most topics in that part are just as relevant for children as for neonates.

*Notes*

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## Operating room, ICU and step-down units

### Carbon dioxide in critically ill adult patients

In Intensive Care Units (ICU), it is vital to continuously monitor arterial carbon dioxide tension. This is commonly performed by analysis of arterial blood gas samples or derived from end-tidal $pCO_2$ measurement. Arterial blood samples require an arterial puncture or insertion of a catheter with the associated risks and inconvenience for the patients. In addition blood gases are only analyzed intermittently. End-tidal $pCO_2$ is a poor predictor of $PaCO_2$, as it normally underestimates $PaCO_2$. The relationship between the two values varies largely, depending on the ventilation-perfusion ratio and cardiac output. Thus, tc$pCO_2$ monitoring is an alternative way of noninvasive estimation of arterial carbon dioxide tension without the drawbacks of end-tidal $pCO_2$ [4, 21].



### tc$pCO_2$/$PaCO_2$ correlation studies

Many TC studies focus on the tc$pCO_2$/$PaCO_2$ correlation; however, the major advantage of the tc$pCO_2$ technique is that it is non-invasive and follows the trends of $PaCO_2$ with less than 1 minute of delay. A number of different TC correlation studies are quoted in the following pages.

A major study tested the tc$pCO_2$/$PaCO_2$ correlation in a wide range of arterial carbon dioxide tension values: 26-71 mmHg (3.4 - 9.4 kPa). The authors found a close correlation ($r= 0.968$, $p < 0.0001$); mean bias was 0.75 mmHg (0.1 kPa) (limits of agreement: –4.5 to +6 mmHg (0.6 to-0.8 kPa).

This study also included a review of 16 other tc$pCO_2$/$PaCO_2$ correlation studies. In general, these studies showed good correlation. The authors state that some errors seemed to be

related to:

- A particular capnograph (in sleep studies)
- Lack of calibration before every measurement
- Not allowing sensor sufficient stabilization time
- Inadequate cutaneous perfusion

It was concluded that tc$pCO_2$ in hemodynamically stable patients was in excellent agreement with $PaCO_2$, and that the response to change in ventilation was compatible with the aim of clinical monitoring of non-invasively mechanically ventilated patients [22].

Two recent studies found a similar correlation with an even wider range of carbon dioxide values: 21-85 mmHg (2.8-11.33 kPa) 38-165 mmHg (5-22 kPa) [60, 61].



So far no studies have evaluated normal or reference tc$pCO_2$ values for different patient groups. This is probably because transcutaneous monitoring is a tool for monitoring carbon dioxide trends [62].

Transcutaneous carbon dioxide monitoring has shown to provide a better estimate of $PaCO_2$ than end-tidal $pCO_2$ during general anesthesia in patients with a body mass index greater than 40 kg/$m^2$ [63].

### Transcutaneous trends in critically ill patients

A new study focused on tc$pCO_2$ trends in critically ill patients, which vary more than 8 mmHg (1.06 kPa) from the corresponding $PaCO_2$ value. The purpose was to evaluate if relevant carbon dioxide changes were indicated in the tc$pCO_2$ trend shift. A trend shift was defined as: A difference between tc$pCO_2$ and $PaCO_2$ that was more than 8 mmHg (1.06 kPa).

They found the following:

| Sensitivity | Specificity | PPV* | NPV* |
|---|---|---|---|
| 86 % | 80 % | 60 % | 97 % |

(*Positive predictive value/negative predictive value)

The patients in the study had septic shock, cardiac arrest, cardiogenic shock and other diagnoses. It was concluded that tc$pCO_2$ provides a safe and reliable trend-monitoring tool if there is no major vasoconstriction [24,25].

### Sustained elevated tc$pCO_2$ in trauma patients

High tc$pCO_2$ values within the first hour of hospital admission were shown to correlate well with mortality in trauma patients. The patients were monitored with tc$pCO_2$ immediately after admission. Early signs of poor tissue perfusion within the first hour could be related to survivors and non-survivors. Sustained elevated tc$pCO_2$ levels for more than 30 minutes were associated with a 100 % mortality rate [4,64].



### High Frequency Oscillatory Ventilation and non-invasive positive pressure ventilation

A combined tc$pCO_2$/$SpO_2$ measurement is relevant in clinical settings of non-invasive positive pressure ventilation and high-frequency oscillatory ventilation (HFOV), where end-tidal $pCO_2$ measurement and clinical assessment can be difficult or impossible. tc$pCO_2$ was also shown to be a useful tool for adjustment of the driving pressure in the jet ventilator for "rigid bronchoscopy patients" during high-frequency jet ventilation (HFJV). This is especially relevant in overweight patients with pulmonary diseases and during long-lasting procedures with endobronchial interventions [66,76].

Since only the proximal airway pressure is monitored during HFOV and HFJV, no alarm will occur in the event of obstruction or restriction of the airways. The technique also induces a risk of hyperventilation resulting in hypocapnia. HFOV manufacturer guidelines recommend tc$pCO_2$ / tc$pO_2$ and $SpO_2$ are measured during treatment. This is particularly important in older children and adults who have more dead space and a greater metabolic demand on ventilation [42].

### Hypercapnic respiratory failure and oxygen therapy

A study evaluating intermittent positive pressure ventilation recommends that patients with hypercapnic respiratory failure in oxygen therapy are assessed with initial arterial blood gases and continual pulse oximetry plus tc$pCO_2$ monitoring during sleep [67].

### One-lung ventilation



Various factors may influence the difference between $PaCO_2$ and end-tidal $pCO_2$ during thoracic anesthesia. Many thoracic surgical patients have some degree of preoperative lung dysfunction and a history of smoking. One-lung ventilation is often used to improve surgical exposure during thoracic procedures. However, one-lung ventilation impairs the ventilation/perfusion matching. Several studies have concluded that patients undergoing one-lung ventilation are significantly better monitored by tc$pCO_2$ than by end-tidal $pCO_2$ [68,69].

### Secondary pulmonary hypertension

Patients with COPD, obstructive sleep apnea and cystic fibrosis sometimes develop secondary pulmonary hypertension. tc$pCO_2$ / (tc$pO_2$) and $SpO_2$ are sometimes used as part of the evaluation of the respiratory status of these patients, neonates, children as well as adults [70,71,72,73].

### Hypotensive shock diagnosed by tc$pO_2$

In one study more than 300 acute episodes of circulatory dysfunction and shock in the ICU were evaluated. It was concluded that "Non-invasive measurements identify early circulatory problems reliably and provide objective criteria for physiological analysis as well as definition of therapeutic goals and titration of therapy". Transcutaneous oxygen and carbon dioxide tensions were used to assess tissue perfusion and oxygenation. The authors refer to several studies that have documented experimentally and clinically that tc$pO_2$ changes with alterations in oxygen metabolism. The authors found that hypotensive shock usually was preceded by episodes of high flow, which was then followed by a period of low flow and inadequate tissue perfusion. The latter was detected by a reduced tc$pO_2$ [74].

Please note that even if transcutaneous oxygen significantly correlates with arterial values, the agreement between tc$pO_2$/$PaO_2$ indicates that it should not be used as a solo estimation of $PaO_2$ in adult patients, however as documented above it can be an early warning of a shock [20, 27].

## Conscious sedation during diagnostic surgery

### Conscious sedation

In a state of moderate or deep sedation (during diagnostic or therapeutic procedures), regular breathing will often be disturbed by moving, squeezing, coughing or changes between nose and mouth ventilation, causing leakage and therefore artifacts or misinterpretation of the data obtained with end-tidal $pCO_2$. These problems often restrict the use of side-stream capnography although the American Society of Anesthesiologists and the American Society of Gastrointestinal Endoscopy suggest in their guidelines that external monitoring with capnography should be considered for patients in conscious and deep sedation [60,65].

In recent years, new anesthetic drugs and advanced interventional techniques have been used increasingly. During moderate sedation, e.g. during colonoscopy, some patients may unintentionally be sedated to a level of general anesthesia. These patients may develop respiratory depression or airway obstruction. In two studies on patients undergoing colonoscopy, $SpO_2$, $tcpCO_2$ and end-tidal $pCO_2$ were used to monitor patient status. Because of supplemental oxygen supply, the pulse oximeter did not show early signs of hypoventilation while $tcpCO_2$ monitoring did indicate prolonged hypoventilation. It was concluded that during moderate sedation $tcpCO_2$ monitoring might provide a better monitoring of the ventilation than end-tidal $pCO_2$; however, airway obstruction was indicated earlier by end-tidal $pCO_2$ [60,65].



### Bronchoscopy and COPD exacerbation

Studies have shown that $tcpCO_2$ often increases while patients are on assisted ventilation during bronchoscopy. Monitoring $tcpCO_2$ assists ventilator adjustments, and is very helpful in assessing patients during the initial periods off the ventilatior. The

authors further states that trending carbon dioxide levels is also relevant in patients with COPD exacerbation [75,76].

### Endoscopy

A randomized, controlled trial evaluated the ability to detect carbon dioxide retention purely by clinical observation or pulse oximetry in patients receiving supplemental oxygen. 395 patients were followed with these two methods and with tc$pCO_2$ during Endoscopic Retrograde CholangloPancreatography (ERCP). Neither clinical observation nor the $SpO_2$ surveillance technique reliably detected carbon dioxide retention. It was concluded that additional tc$pCO_2$ monitoring prevented severe carbon dioxide retention more effectively. In 10 % of the patients who received supplemental oxygen, $SpO_2$ did not indicate desaturation even though tc$pCO_2$ increased by more than 20 mmHg. Furthermore, tc$pCO_2$ monitoring facilitates a slightly deeper mean sedation and a significantly shorter duration of inadequate sedation. The overall doses of sedative and analgesic drugs were the same irrespective of the chosen surveillance technique. This indicated that transcutaneous carbon dioxide tension monitoring provided a more precise titration and timing of these drugs during ERCP [77].



Notes




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## Pulmonary/respiratory medicine laboratory or wards

### COPD

Chronic Obstructive Pulmonary Disease (COPD) is a major cause of respiratory morbidity, The European Commission for Public Health characterizes COPD as a leading cause of chronic morbidity and the US National Institutes of Health list it as the fourth-leading cause of death in the US [78].

COPD patients are often old and hospitalized repeatedly for longer or shorter periods of time, and it is therefore important to minimize the interventions and use non-invasive surveillance. Monitoring of the carbon dioxide tension level by a combined tc$pCO_2$/$SpO_2$ probe is, according to the studies mentioned below, often the right choice.



### Carbon dioxide monitoring in COPD and other respiratory patients

A study compared $PaCO_2$ with arterialized capillary blood ($PacCO_2$), tc$pCO_2$, end-tidal $pCO_2$ and physiological respiratory dead space-to-tidal volume (VD/VT) ratio in COPD patients, postoperative cardiac surgery patients and healthy control subjects. Patients were evaluated at three mechanical ventilator patterns. $PaCO_2$, tc$pCO_2$, end-tidal $pCO_2$ correlated well with VD/VT and $PaCO_2$ (0.99, 0.97 and 0.87). However, other studies have demonstrated that end-tidal $pCO_2$ is inaccurate in patients with ventilation/perfusion mismatch [21,27,79].

## COPD exacerbation during oxygen therapy

Hypoxic patients with acute exacerbation of COPD are, according to studies and the guideline "The ABC of oxygen therapy", at risk of carbon dioxide retention when they receive oxygen therapy. A combined tc$pCO_2$/$SpO_2$ measurement has shown to be useful in clinical settings of non-invasive positive pressure ventilation, where end-tidal $pCO_2$ measurement and clinical assessment can be difficult. In Fig. 9, an example of monitoring of a COPD patient is shown [76,80].

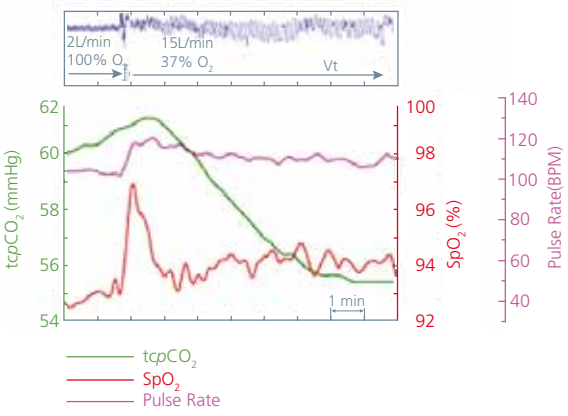


**FIG. 9: COPD patient during high-flow oxygen in sufflation.**
A COPD patient, monitored by continuous tc$pCO_2$/$SpO_2$ and pulse rate, during delivery of a transtracheal high-flow oxygen insufflation. The ventilation was measured by means of a respiratory inductive plethysmograph (Vt = change of lung volume). [81].

### Ventilator manipulation according to tc$pCO_2$

A study found tc$pCO_2$ measurements was appropriate for estimating the ventilatory response to Non-Invasive Ventilation (NIV) in patients with hypercapnic ventilatory failure due to acute exacerbation of chronic obstructive pulmonary disease (AECOPD) [61].

### Nocturnal oxygen desaturation in patients with COPD

Nearly 80 % of patients with severe chronic COPD experience nocturnal oxygen desaturation due to hypoventilation. The consequence is an increased arterial carbon dioxide tension, and it may result in nocturnal and daytime symptoms of respiratory failure, cor pulmonale, etc. These patients might benefit from tc$pCO_2$ monitoring during the night, when started on oxygen therapy.



Continuous non-invasive assessment of carbon dioxide tension is crucial in the sleep lab for diagnosis and treatment of patients with severe COPD. A study has shown a strong correlation between daytime levels of $PaCO_2$ and the severity of hypoventilation during the night, i.e. high daytime levels of carbon dioxide are more likely to lead to hypercapnia during the following night. A similar relationship between night- and daytime hypoventilation was seen in a randomized, controlled multicenter trial, where many patients' hypercapnia was detected by a tc$pCO_2$ measurement. This study documents that stable COPD patients' daytime $PaCO_2$ levels can be improved by tc$pCO_2$ - based adjustments of the nocturnal non-invasive ventilation. An example of a patient measurement from this study is shown in figure 10 [67,78,82].

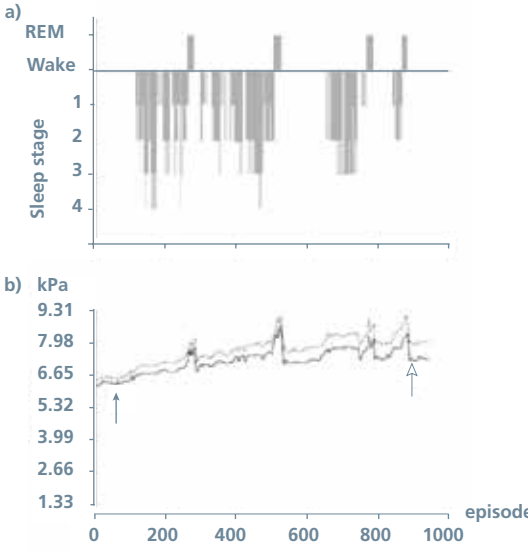




**FIG. 10: A nocturnal patient measurement**
a) Sample hypnogram showing the patients' stage of sleep.
b) Nocturnal tc$pCO_2$ recordings. Note the correlation between an elevated tc$pCO_2$ and REM (rapid eye movement) sleep. The time is indicated on the x-axis in periods of 30 sec duration. The closed arrow shows episode 55 (tc$pCO_2$: 6.61 kPa (49.7 mmHg) and $PaCO_2$: 6.29 kPa (47.3 mmHg)); Open arrow indicates episode 923 (tc$pCO_2$: 8.09 kPa (60.8 mmHg) and $PaCO_2$: 7.39 kPa (55.6 mmHg)).”– “ = tc$pCO_2$ with in vivo calibration and “·····” = tc$pCO_2$ without in vivo calibration. (Copyright obtained from Eur Respir J) [78]

## Acute Respiratory Distress Syndrome (ARDS)

In a study on patients with various respiratory conditions it was concluded that tc$pCO_2$ provides a better indication of ventilation status than end-tidal $pCO_2$. The authors write that this is due to an increased dead space ventilation or ventilation in excess of perfusion. Under these circumstances (high V/Q mismatch) the carbon dioxide may be inadequately removed from the bloodstream and the $PaCO_2$ will increase without an equivalent increase in the end-tidal $pCO_2$. The discrepancy be-

tween arterial and end-tidal $pCO_2$ is particularly large in ARDS patients [83].

### Non-invasive ventilation

Increasing evidence of the benefits of Non-invasive Positive Pressure Ventilation (NPPV) in a variety of pulmonary disorders has led to its widespread use. tc$pCO_2$ was shown to be in excellent agreement with $PaCO_2$ in hemodynamically stable adults. Also the time for a change in ventilation to be detected by tc$pCO_2$ measurements was shown to be compatible with the aim of clinical monitoring of patients under NPPV [22].

### Leaks during non-invasive positive pressure ventilation

It has been documented that many non-invasively ventilated patients have clinically relevant mouth or other air leaks, and this should therefore be measured routinely. The leaks are especially seen if nasal resistance is high, if treatment is not optimum or if sleep architecture appears to be impaired. A study on awake control subjects has confirmed that a large mouth leak is very distressing and is a likely cause of severe sleep disruption. Sleeping patients with a mouth leak during nasal bi-level ventilatory assistance have been found to have an increased tc$pCO_2$ [84].



### One-lung ventilation

Several studies have shown that transcutaneous monitoring of carbon dioxide tension provides a more accurate estimation of the $PaCO_2$ during one-lung ventilation (OLV) than end-tidal $pCO_2$ measurements. The table below, taken from one of these studies shows a significantly larger difference between the end-tidal $pCO_2$ and $PaCO_2$ compared with the difference between the tc$pCO_2$ and $PaCO_2$ in patients with 1 hour of OLV during thoracic anesthesia.

| Time | Difference in mmHg relative to $PaCO_2$ | |
|---|---|---|
| Minutes of OLV | End-tidal $pCO_2$ | tc$pCO_2$ |
| 15 | 6.1 ± 4.6 * | 0.0 ± 2.5 |
| 30 | 5.3 ± 4.1 * | 0.0 ± 2.4 |
| 45 | 5.5 ± 3.7 * | 0.2 ± 2.3 |
| 60 | 6.3 ± 4.1 * | 1.3 ± 2.6 |

The values are expressed as difference ± SD (* significant difference $P < 0.05$) [72].

This study also found this significant difference in the two-lung ventilation technique: end-tidal $pCO_2$ – $PaCO_2$: –7.1 ± 4.6 mmHg versus tc$pCO_2$ – $PaCO_2$: 1.4 ± 4.3 mmHg [68,69].

### Respiratory testing

For asthma patients, some doctors find that measurement of non-specific bronchial hyperreactivity caused by inhaled bronchoconstrictor agents provides important research and diagnostic aid.



tc$pCO_2$ monitoring has proven to provide a useful and reliable tool for analysis of the slope of dose-response curves to inhaled methacholine in asthmatic adult patients [85,86].

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## Sleep laboratories

### Sleep apnea

Sleep apnea affects people worldwide. According to a WHO estimations 5-20 million people in Europe and 15-20 million in the US are affected by this disease and 11 % of the US obstructive sleep apnea patients also have COPD. If untreated, these patients suffer from excessive daytime sleepiness and impaired cognitive performance. There is also an increased risk of causing traffic accidents and suffering from cardiovascular diseases. Continuous non-invasive monitoring of the $SpO_2$ levels and trends have proven to be crucial in the sleep laboratory for diagnosis and treatment of these patients. Correspondingly, tc*p*$CO_2$ monitoring is useful to detect hypoventilation [76,77, 78].



### Episodes of hypoventilation

In order to avoid potentially dangerous hypoventilation or suboptimum nocturnal ventilatory assistance, a combined tc*p*$CO_2$/$SpO_2$ measurement is useful in clinical settings using non-invasive positive pressure ventilation. Episodes of hypoventilation lasting as little as 30 seconds were detectable by the tc*p*$CO_2$ monitoring [76,78].

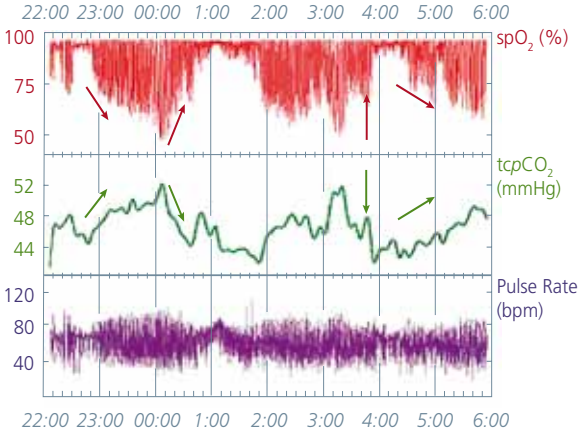


**FIG. 11: Nocturnal recording**
An example of nocturnal recording in a patient with obesity-hypoventilation and sleep apnea syndrome. Recordings were done between 6 pm and 6 am with a combined tc$pCO_2$/$SpO_2$ earlobe sensor. The arrows illustrate how well $SpO_2$, tc$pCO_2$ and the pulse rate reflects events of hypoventilation and resumption of normal ventilation, respectively [81].



### Cystic fibrosis

Patients with advanced cystic fibrosis may develop hypoxia and hypercapnia during sleep, particularly during REM sleep. Elevated evening levels of $PaCO_2$ were found to be associated with both sleep-related desaturation and the rise in tc$pCO_2$ in periods of NREM-to-REM sleep in these patients [88].

### Patients undergoing long-term non-invasive ventilation

Long-term nocturnal non-invasive ventilation improves daytime symptoms of hypoventilation, sleep quality and respiratory failure even when patients are not on ventilatory support. tc$pCO_2$ monitoring is an important tool to evaluate effectiveness of treatment and adjust ventilator settings [89].

### Leaks in ventilation

As mentioned in the section on pulmonary medicine, patients on noninvasive positive pressure ventilation often have leaks from the mask or through the mouth. This may disturb the sleep architecture. The associated increases in the carbon dioxide level can be detected by tc$pCO_2$ monitoring [82].

*Notes*

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## Veterinary hospitals/laboratories

### Animals

Although transcutaneous monitoring was originally developed for human use, the literature has shown several examples of its use on animals. Before TC measurement it is necessary to prepare the skin, in order to optimize the conditions for carbon dioxide and oxygen diffusion through the skin. Removing the hair and the upper layer of dead skin cells is therefore advised. Do not use any kind of chemicals for hair removal, as they will affect the measurements. On larger animals like pigs, some authors recommend that the relevant skin area is carefully rubbed with sand paper to prepare the skin for the measurement (after the hair has been removed) [90].

### tc$pCO_2$ - $PaCO_2$ correlation in mice and rats

A linear relationship between tc$pCO_2$ and $PaCO_2$ was seen in mice and different races of rat [91].



### Skin viability in dogs

A study concludes that transcutaneous oxygen is useful for assessing skin viability in dogs [92].

### Hemorrhagic shock in pigs

Twelve-week-old pigs were used for evaluating the severity of hemorrhagic shock. Together with measuring pH in the intramucosal wall, transcutaneous monitoring of oxygen indicated blood volume loss more rapidly than, for example cardiac output [90].

### Not all animal studies show good results

Some animal studies have shown suboptimum results. This may be due to improper preparation of the animal's skin, or limitations of the TC technique. It is therefore recommended to conduct a validation of the measurements before new kinds of animal studies or clinical uses are initiated.

### Experimental use of the TC technique

Experimental use of the TC technique sometimes requires new ways of thinking. An example of this is an unpublished case story based on TC intestinal oxygen measurement in a horse undergoing ileus surgery. As the intestine is wet and moving, it is impossible to use fixation rings for attaching the sensor during surgery. The veterinarians used a clean (but not sterilized) tc$pO_2$ sensor with a new membrane. They used a sterile glove, where they cut a hole for the head of the sensor, so the sensor could be placed directly on the moving intestine without contact gel or liquid. The measuring temperature was low to avoid burns. This method enabled them to decide where the tissue had sufficient levels of oxygen and where the oxygenation was too low. The operation went well; afterwards the horse was treated with antibiotics, and it did not show any signs of infection [*].

* Not published material.



*Notes*

90. Hartmann M, Montgomery A, Jönsson K et al. Tissue oxygenation in hemorrhagic shock measured as transcutaneous oxygen tension, subcutaneous oxygen tension, and gastrointestinal intramucosal pH in pigs. Critical care Medicine 1991; 19,2: 205-10.
91. Ramos-Cabrer P, Weber R, Wiedermann D *et al*. Continuous noninvasive monitoring of transcutaneous blood gases for a stable and persistent BOLD contrast in fMRI studies in the rat. NMR in Biomed 2005; 18: 440-46.
92. Rocbat MC, Pope ER, Payne JT et al. Transcutaneous oxygen monitoring for predicting skin viability in dogs. Am J Vet Res 1993; 53, 3: 468-75.



68

# Use of the TCM4/40/ TOSCA/CombiM monitors

**A short overview of TCM4/40/TOSCA/CombiM monitors**

This section of the handbook gives a short overview of how to work with the TCM4/40/TOSCA/CombiM monitors. For further information, please refer to the "*operator's manual*" for these monitors.

**Measurements**

During monitoring, the results can be viewed as current numeric results, curves, and trend tables. The monitor stores data up to 48 hours of monitoring data. It is possible to print out the data or send it to an external computer.

# Menu structure of the TCM4/40/ TOSCA/CombiM monitors

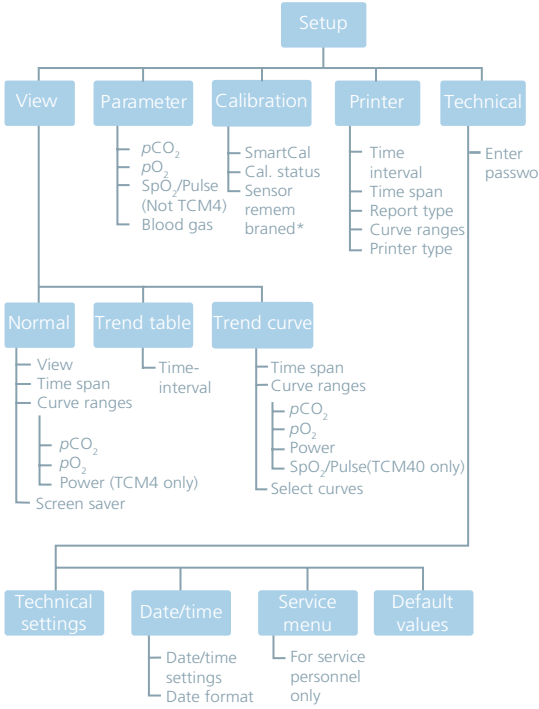



**Fig. 12: Menu structure of the TCM4/40/TOSCA/CombiM monitors**

***Only on the TCM TOSCA/CombiM monitors**

# Short-form support for the TCM4/40/ TOSCA/CombiM monitors

⚠ Please consult the "*operator's manuals*" for instructions.

This short-form support provides only a brife overview when using the device please consult "*operator's manuals*"

Applicable for
The following short-form instructions are valid for monitors with base unit model 391-876 or later.

Start-up
Turn on the power supply on the rear of the monitor and then press the ⏻ button on the front of the monitor.

Shutdown
Press the ⏻ button on the front of the monitor. Then press **OK** on the screen.

*Note:* If the power switch on the rear is ON, the battery will be recharged when needed.

Calibration
Insert the sensor in the calibration chamber and press **Calibrate**.

*Note:* Make sure the sensor is placed correctly in the chamber and that the arm is positioned horizontally across the sensor.

SmartCal
The SmartCal function makes sure the monitor is always ready for monitoring by calibrating when needed.



**To be continued page 72**

Follow these steps to enable/disable SmartCal:

1. Press ***Setup*** → ***Calibration*** → ***SmartCal***.
2. Use the blue arrow key to select the "SmartCal ON/OFF" option.
3. Use the black arrow keys to set the option to ON or OFF.
4. Use the blue arrow key to select the "SmartCal duration" option.
5. Use the black arrow keys to select the duration of the SmartCal period.
6. Press ***OK***.

*Note:* Although the option is enabled, it is necessary to press Calibrate to start a new SmartCal period.

*Note:* If SmartCal is not activated, the monitor is calibrated manually by pressing Calibrate.

SmartHeat

The SmartHeat TCM4/40 function increases the sensor temperature by 1 °C (1.8 °F) NB. max. temp. 45 °C in a period of five minutes after the sensor has been removed from the calibration chamber. As a result, the tc$pO_2$/tc$pCO_2$ values can be read within 8-12 minutes after sensor placement on the patient. Follow these steps to enable/disable SmartHeat:

1. Press ***Setup*** → ***Parameter*** → ***p*CO$_2$** or ***p*O$_2$**.
2. Use the blue arrow key to select the "SmartHeat" option.
3. Use the black arrow keys to set the option to ON or OFF.
4. Press ***OK***.

*Note:* The setting of this option is common to ***p*CO$_2$** and ***p*O$_2$**.

| | |
|---|---|
| Adjustment of $pCO_2$ and $pO_2$ alarm limits | 1. Press ***Setup*** → ***Parameter*** → ***$pCO_2$*** or ***$pO_2$***. (Alternatively just Press on the required Parameter)<br>2. Use the blue arrow key to select the "Alarm high/low" options.<br>3. Use the black arrow keys to adjust the values.<br>4. Press ***OK***. |
| Adjustment of $SpO_2$ and pulse alarm limits | 1. Press ***Setup*** → ***Parameter*** → ***$SpO_2$/Pulse***. (Alternatively just press ***Parameter***)<br>2. Use the blue arrow key to select the $SpO_2$ alarm high/low" and "Pulse alarm high/low" options.<br>3. Use the black arrow keys to adjust the values.<br>4. Press ***OK***. |
| Settings for SatSeconds* | 1. Press ***Setup*** → ***Parameter*** → ***$SpO_2$/ Pulse for TCM40.***<br>2. Use the blue arrow key to select the "SatSeconds" option.<br>3. Use the black arrow keys to adjust the value.<br>4. Press ***OK***.<br>For a description of the SatSeconds function, see the TCM4/40 *"operator's manual"*. |
| Silencing of alarm for all parameters | Press ***Alarm silence*** to silence the alarm for 2 minutes.<br>Follow these steps to disable the alarm continuously:<br>1. Press ***Setup*** → ***Parameter*** →***$pCO_2$*** or ***$pO_2$*** or ***$SpO_2$/Pulse***. |



**To be continued page 74**

2. Use the blue arrow key to select the "$pCO_2$ -", "$pO_2$ -", "$SpO_2$ -" or "Pulse alarm" option.
3. Use the black arrow keys to set the option to ON or OFF.
4. Press ***OK***.

Alarm symbols

The alarm symbols in Normal view have the following meanings:

Alarm is off 

Alarm is on 

Site time

The site timer is typically activated when the sensor is affixed to the patient. The site time function can be used to indicate that the sensor must be moved to another site, that medication should be given or that a monitoring period is finished. The site timer will count down to zero at 1 minute intervals, and when it reaches zero, the message "Site time end" will be displayed on the screen.

Follow these steps to adjust the Site time:

1. Press ***Setup*** → ***Parameter*** → ***pCO₂*** or ***pO₂***.
2. Use the blue arrow key to select the "Site time" option.
3. Use the black arrow keys to set the timer.
4. Press ***OK***.

*Note:* If Site time heat is set to OFF in the setup, the sensor heat is switched off when the site timer reaches zero and the TCM4/40 monitors stops monitoring; if set to ON, the heat continues.

*Note:* The setting of this option is common to $pCO_2$ and $pO_2$.

| | |
|---|---|
| Marking of event | Press ***Event*** → ***OK*** to mark an event (for instance when giving medicine). The event number will be added in the Normal, Trend table and Trend curve views. |
| Views | In order to view the desired data format on the monitor, press ***Setup*** → ***Normal*** or ***Trend table*** or ***Trend curve*** → ***OK***.<br>In Trend table view, current values as well as historical values are presented. In Trend curve view, the high and low values of the ranges can be changed with the arrow keys next to the actual parameter. |
| Cursor in Trend curve view | In Trend curve view, press ***Cursor*** to add a cursor to the screen.<br>The cursor values ($pCO_2$, $pO_2$, Power, $SpO_2$, Pulse, Time and Date) are shown in the lower right part of the screen, whereas current values are shown in the upper right part of the screen. When the cursor is moved all the way to the left, the time axis changes and it is possible to go back in time. |
| Gas status | When there is 10 % or less gas left in the gas cylinder, the present gas level is shown in a bar during calibration. It is recommended to change the gas cylinder when the bar appears. |
| Change of | 1. Unscrew the old gas cylinder by turning it gas cylinder counter clockwise.<br>2. Remove the white protection cap on the new gas cylinder and screw the new gas cylinder clockwise as far as possible into the socket. |

**Battery**

If the monitor is running on battery, the remaining power is indicated at the top of the screen by the following symbols:

full  , almost full  ,

low  and critically low  .

**Alarm sound level**

1. Press ***Setup*** → ***Parameter*** → ***pCO$_2$*** or ***pO$_2$*** or ***SpO$_2$/Pulse***.
2. Use the blue arrow key to select the "Alarm sound level" option.
3. Use the black arrow keys to adjust the volume.
4. Press ***OK***.

*Note:* The setting of this option is common to *p*CO$_2$, *p*O$_2$ and SpO$_2$.

**Adjustment of date/time**

1. Press ***Setup*** → ***Technical*** (enter password "19100") → ***Enter*** → ***Date/time***
2. Adjust the date and time.
3. Press ***OK***.

**Change units between kPa and mmHg.**

1. Press ***Setup*** → ***Technical*** (enter password "19100") → ***Enter*** → ***Units pCO$_2$/pO$_2$ kPa/mmHg***
2. Adjust the units.
3. Press ***OK***.

**Adjustment of default values**

Adjust the default values – e.g. the unit (kPa/mmHg), the alarm limits, the curve ranges and the temperature – in order to match your local needs.

*Note:* Under technical setting it is possible to choose standard values. By pressing this button many of your settings (parameter limits, measuring time, curve view, etc.) can be changed! For complete instructions, see the operator's manual or play the totorials in the monitor.

**Conversion factors**

1 mmHg = 1 Torr = 0.133322 kPa [93]

## How to apply tc sensors

### Sensors in fixation rings

1. Calibrate the tc sensor.
2. It is recommended to clean the selected measuring site with alcohol or other skin-preparation solution and, if necessary, shave the area. This will help the ring to stick better to the skin or prevent air from leaking into the fixation ring.
3. Dry the site well.
4. Take a fixation ring.
5. Remove the fixation ring from the protective film.
6. Apply the fixation ring to the measuring site as follows:
   - Press the center of the fixation ring onto the measuring site with a finger
   - Run a finger around the rim circumference



*Note:* It is important to press firmly to avoid introduction of atmospheric air under the fixation ring. Because of the difference between physiological tc*p*$O_2$ and tc*p*$CO_2$ and atmospheric concentrations of 20.93 % $O_2$ and 0.03 % $CO_2$ (*), the tc*p*$O_2$/tc*p*$CO_2$ values are easy to differentiate.

7. Fill the well in the fixation ring with 3-5 drops of the contact liquid or one drop of contact gel.
8. Affix the sensor into the fixation ring by aligning the arrow on the sensor with one of the marks on the fixation ring. Turn the sensor 90° clockwise to fasten it in the fixation ring (E5250-E5480), or click in the sensor (54-TOSCA92).

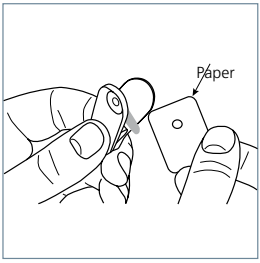
Wait for a stable reading after the sensor has been affixed to the patient.

By choosing SmartHeat on the TCM4/40 monitors, the physiological stabilization time will fall to 5-16 minutes for the tc*p*$O_2$ and to 3-6 minutes for the tc*p*$CO_2$.

(*At sea level and at a pressure of 1 atmosphere)

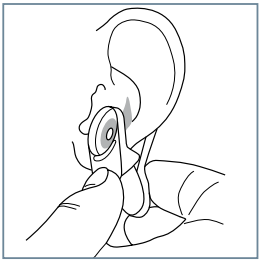
## How to place the ear clips and earlobe sensors


1. Clean the ear lobe with alcohol swab.

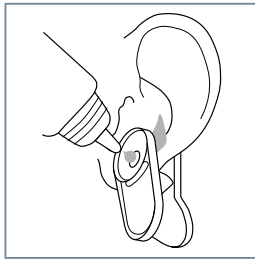



2. Take an attachment clip and remove the white cover.





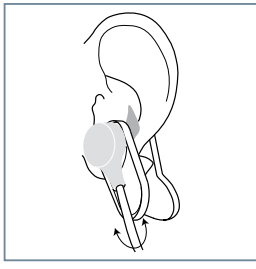
3. Attach the clip to the fleshy part of the ear lobe (with the retainer ring pointing outwards). Squeeze gently to ensure that the adhesive area sticks firmly to the ear lobe. Make sure that no air is under the adhesive area.



4. Apply two drops of contact gel to the visible skin area in the center of the retainer ring; just enough to slightly wet it.

5. Remove the sensor from the calibration chamber and insert it into the retainer ring of the clip.
   Press slightly until it snaps in.





6. Twist the sensor into the best position. Make sure that the sensor cable is loose and will not be stretched during monitoring. Route the sensor cable properly to avoid strangulation To ensure prober fixation of the sensor, twist the sensor carefully a quarter of a turn.

## Calibration

**When to calibrate**

Radiometer recommends performing a calibration on the TCM4/40 monitors:

- prior to each monitoring period
- when changing measuring sites
- every 4 hours (TCM4/40*) or every 8-12 hours (TCM/TOSCA/CombiM)*)
- every time an sensor has been remembraned

After a membrane change and after the TC monitor is switched on, it is recommended to calibrate the sensor twice, with a 30 minute break between the two calibrations, before a new measurement. This will minimize the sensor drift.

### *In vivo* calibration

*In vivo* calibration is an adjustment of the initial tc$pCO_2$/tc$pO_2$ values to the initial arterial blood gas values. This is done by moving the shown TC values up or down to the initial measured $PaO_2$/$CO_2$ levels. In order to perform an *in vivo* calibration, it must be selected in the setup. Draw an arterial blood gas sample at the beginning of a stable TC monitoring period and press the blood gas button. When the sample has been analyzed on a blood gas analyzer, the measured blood gas values must be typed into the TC monitor.



*) In a study of 8 hours of continuous monitoring of tc$pCO_2$ with this TC sensor the author concludes that the measurements gave reliable results during the 8 hours without any significant drift. In this study they changed the membrane every 48 hours. Therefore this is a possibility but this is however, not according to the above recommendations for that sensor. As an alternative one could also use the TCM/TOSCA/CombiM sensors that only has to be calibrated every 8-12 hours. [94]

In the literature there have been discussions about the need for *in vivo* calibration. In patients with severe head and brain injury, the increase in $PaCO_2$ level may lead to increased cerebral blood flow and augmenting brain edema. In these patients one author recommends performing an *in vivo* calibration at the beginning of the monitoring period and stresses the need to check it regularly. (However, other authors prefer not to use *in vivo* calibration when they work with $tcpCO_2$ monitoring.)

The study only had 12 COPD patients enrolled. The authors concluded: *"$tcpCO_2$ values and variations accurately reflected $PaCO_2$ values and that this seems to be restricted to patients with $PaCO_2$ values below 56 mmHg".* However, the study only had one patient with $PaCO_2$ readings up to 56 mmHg, which makes this part of the conclusion questionable. This might also be the reason why this limited correlation was not confirmed in any of the larger studies mentioned earlier in this handbook. The authors explained the incidence by a too low electrode temperature and they advise the readers to perform an *in vivo* calibration* when they use TC monitoring. [78,95].



Please note that in *vivo* calibration does not make the TC monitor read arterial values, nor does it eliminate the blood flow or any other determinants that TC values depends on. Although an arterial blood gas in many situations is the "gold standard", there is always a risk of a preanalytical error in the blood sample that is used for the in *vivo* calibration. Furthermore, an in *vivo* calibration requires a new blood sample with every change of measuring site or sensor temperature and the sensor still needs regular calibration due to sensor drift. TC measurements show trends, not absolute values, initially the trends show an actual arterial blood gas value, but it might not be accurate in the end of the measuring period. For more information please refer to the operator manuals [21, 78, 95].

21. Bendjelid K, Schütz N, Stotz M et al. Transcutaneous $pCO_2$ monitoring in critically ill adults: Clinical evaluation of a new sensor. Crit Care Med 2005; 33, 10: 2203-06.
78. O'Donoghue FJ, Catcheside PG, Ellis EE *et al*. Sleep hypoventilation in hypercapnic chronic obstructive pulmonary disease: Prevalence and associated factors; Eur Respir J 2003; 21: 977- 84.
93. www.concert-me.com/en/convert/units/pressure/pressure.mm*mercury.en.html
94. Janssens JP, Perrin E, Bennani I *et al*. Is continuous transcutaneous monitoring of $pCO_2$ ($tcpCO_2$) over 8 h reliable in adults? Respiratory Medicine 2001: 95.
95. Cuvelier A, Grigoriu B, Molano LC, Muri J-F *et al*. Limitations of transcutaneous carbon dioxide measurements for assessing long-term mechanical ventilation. Chest 2005; 127: 1744-48.

# Cleaning

## Cleaning

Wipe the following parts gently with a soft cloth moistened with skin antiseptic, e.g. 70 % alcohol:

- sensor head
- cable

*Note:* Use of hand lotion containing isopropanol/propylalcohol and alcohol prior to handling the sensor may damage the cable. To avoid transferring lotion to the cable, dry your hands before handling the sensor.

## Cleaning the exterior

When cleaning the monitor:

- Shut down the monitor
- Use a cloth that has been lightly dampened with soapy water or a mild detergent
- Do not use abrasive cleansers or pads; the finish may become damaged
- Do not use ethanol-based substances or aggressive detergents. Extensive use may cause the plastic to become brittle and cracks may occur



## Cleaning the touch screen

A dry or lightly dampened soft, lint-free cloth may be used to clean the monitor's touch screen. Simply wipe the screen gently to remove fingerprints and/or dirt. To avoid streaking on the screen, an approved screen cleaner is recommended.

## Disinfection

Immerse the sensor and the cable in a 2-3 % aqueous solution of active dialdehydes.

*Warning:* Do not immerse the sensor plug in the disinfection solution, as this will cause the sensor to fail.

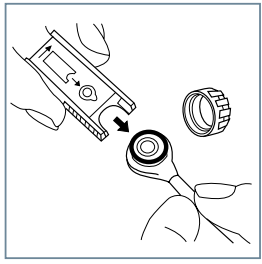
*Warning:* Do not heat sterilize as the sensor cannot tolerate temperatures exceeding 70 °C (158 °F), as this will cause the sensor to fail.

# Maintenance of the sensors

## Manufacturer's recommendation for the sensor

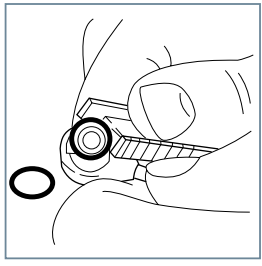
For optimum measurements with the E5250 ($O_2$), E5260 ($CO_2$), E5280 ($O_2$/$CO_2$) and E5480 (neo. $O_2$/$CO_2$) sensors a weekly change of the sensor membrane is recommended*. The TC sensor 54 ($CO_2$), TC sensor 84 ($O_2$/$CO_2$) and TOSCA sensor 92 ($CO_2$/$SpO_2$) must be remembraned every 14 days.

## Changing the membrane on the E5250-80 sensors



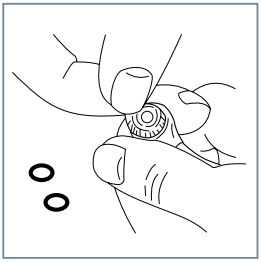
1. Remove the old O-rings: Slide the O-ring remover under the O-ring, just above the arrow on the sensor house.



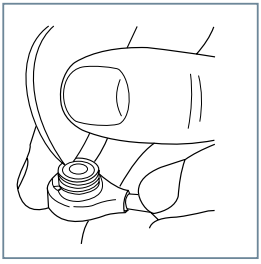


2. Turn the O-ring remover clockwise and counter clockwise to release the two O-rings.
   It is easiest when the sensor is supported against a table.

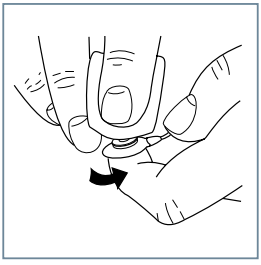
*However, in one study the authors write that by more frequent membrane change (i.e. after a maximum of two continuous 8-hour recordings or when the calibration process is unusually long) the agreement between $PaCO_2$ and $tcpCO_2$ values increases even more [27].



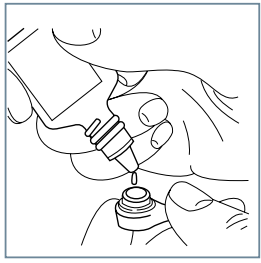
3. Peel off the old membrane. Note that there are two membranes if it is a combined tc$pCO_2/O_2$ sensor.



4. Clean the sensor surface: Absorb the old electrolyte solution with the cleaning paper in the groove.

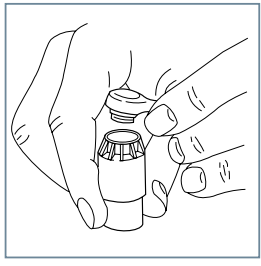


5. Rub the sensor measuring surface carefully two or three times to remove the thin layer of silver that has precipitated on the sensor.



6. Apply two drops of the electrolyte solution on the surface of the tc-sensor.

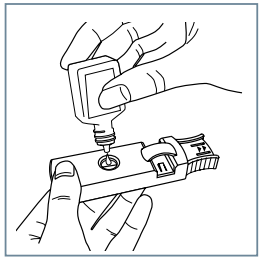
   *Note:* Check that the electrolyte solution covers the entire surface without air bubbles.



7
- Place the membrane unit on a hard and stable surface.
- Turn the sensor slowly so that the measuring surface faces downwards. If the electrolyte solution drops off go back to step five.
- Insert the sensor head into the top of the TC membrane unit.

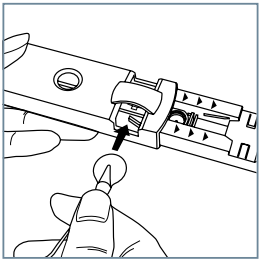


## Changing the membrane on the E5480 sensor

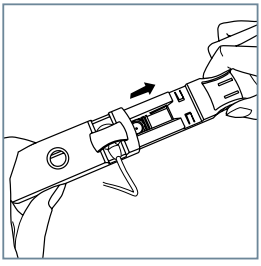


1. Apply two drops of electrolyte solution to the membraning tool.

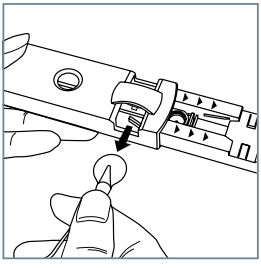
   *Note:* Ensure that there are no air bubbles in the electrolyte solution. If air bubbles are present, wait a few seconds and check again.



2. Place the sensor (without the protection cap) in the sensor slot.

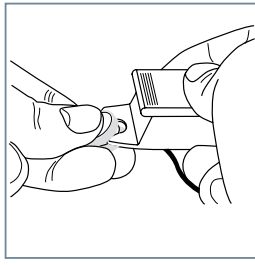


3. To remove the old membrane, grip the membraning tool firmly at both ends. Pull in the direction of the arrows until only one arrow is visible in the sensor slot. To click on the new membrane, pull forcefully in the direction of the arrow until the tool is locked and no arrows are visible in the sensor slot.



4. Remove the sensor and wipe off the surplus sensor solution with cleaning paper. Calibrate the sensor twice before use.

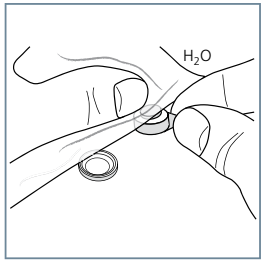
## Changing membrane on the tc sensor 54, tc sensor 84 and tc sensor 92



1. Ensure that the sensor is connected to the monitor, which must be turned on. Remove the old membrane retainer ring assembly using the V-shaped notch in the base of the membraning tool. The cable has to point downwards under the membraning tool. Press the membraning tool down while the electrode is kept in place with the other hand and the old membrane is rejected.

   *Note:* A new sensor is delivered without membrane. In this case start with step two.



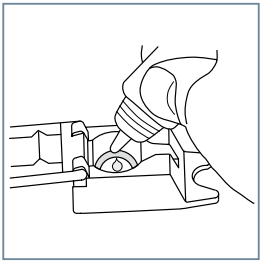



2. Clean the sensor surface with a tissue soaked in clear water. This will also remove the spacer. Dry the sensor surface and make sure that no fibers remain from the tissue.

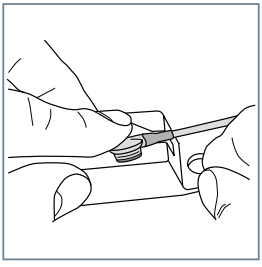
   *Note:* Do not leave an unprepared sensor in air. Proceed immediately with the next step.

SENSOR
REMEMBRANED
+ YES +
- NO -

3. This message appears on the monitor. Leave unanswered until step eight.

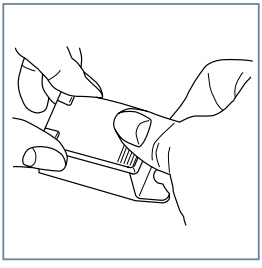


4. Lift up the cover of the membraning tool and place two drop of electrolyte solution (that match the sencor numbers) into the center of the retainer ring assembly.

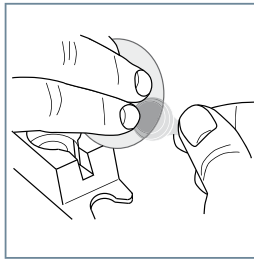


5. Insert the sensor (with its surface pointing downwards) into the preparatory base until it is slightly locked. Do not apply pressure.





6. Close the cover of the membraning tool and press down until the new retainer ring clicks into place. Open the cover, remove sensor and discard membraning tool.



7. Clean excess electrolyte from the side of the sensor.

8. Press “+” on the monitor to confirm the new sensor remembraning. The date is stored in the sensor memory.

CALIBRATING
38 mmHg
CAL - Gas
0% 100%

9. Lift up the lever of the calibration chamber and insert the sensor with its surface pointing downwards as far as it will go. Release the lever. The message: “calibrating sensor” appears. When the calibration is completed the message: “ready to use” appears. The sensor is now ready for measurements.

## List of abbreviations

| | |
|---|---|
| AARC: | American Association of Respiratory Care |
| ARDS: | Acute respiratory distress syndrome |
| BMI: | Body mass index ($kg/m^2$) |
| °C: | Degrees Celsius |
| CPAP: | Continues positive airway pressure |
| COPD: | Chronic obstructive pulmonary disease |
| End-tidal $CO_2$: | End-tidal concentration of $CO_2$ |
| °F: | Degrees Fahrenheit |
| HFJV: | High-frequency jet ventilation |
| HFOV: | High-frequency oscillatory ventilation |
| HHb: | Deoxygenated hemoglobin |
| ICU: | Intensive care unit |
| IR: | Infrared |
| kPa: | Kilo Pascal |
| LED: | Light-emitting diode |
| mm Hg: | Millimeters of mercury, (the same as Torr) |
| NPPV: | Non-invasive positive pressure ventilation |
| NPV: | Negative predictive value |
| Nm: | Nanometer |
| $O_2Hb$: | Oxygenated hemoglobin |
| $PaCO_2$: | Arterial $CO_2$ tension |
| $PaO_2$: | Arterial $O_2$ tension |
| $PcaCO_2$: | Capillary $CO_2$ tension |
| BiPAP: | Bi-level positive airway pressure ventilation |
| PPV: | Positive predictive value |
| Prs: | Respiratory resistance measured by oscillation |
| Rint: | Interrupter technique for measuring respiratory resistance |
| $SpO_2$: | Saturation measured by pulse oximetry |
| sRaw: | Whole-body plethysmography measurements for specific airway resistance |
| TC: | Transcutaneous |

| | |
|---|---|
| tc$pCO_2$: | Transcutaneous $pCO_2$ |
| tc$pO_2$: | Transcutaneous $pO_2$ |
| tc$pCO_2/O_2$: | Transcutaneous $pCO_2$ and $O_2$ |
| UV: | Ultraviolet light |
| VD/VT : | Physiological respiratory dead space-to-tidal volume ratio |
| V/O.: | Ventilation/perfusion ratio |
| Xrs5: | Respiratory reactance measured by oscillation |

# Complementary techniques

The following is a summary of different monitoring techniques that complement transcutaneous monitoring.

### Arterial blood gas samples

Assessment of the alveolar ventilation and arterial oxygen saturation in critically ill patients requires frequent arterial blood gas samples [21].

Arterial blood gas analyses are the gold standard in the ICU and step-down units. However, it is invasive, painful and it can, in very rare situations, result in serious complications (like nerve injury, arterial thrombosis and ischemia leading to necrosis). Furthermore, a blood sample only provides a momentary picture of the $PaCO_2$/$PaO_2$ status if free of preanalytical errors, it does not show continuous gas values. For neonatal patients it is advisable to minimize the amount of blood samples due to the patient's small blood volume, to reducing the need for blood transfusion that may lead to severe complications. Despite this, arterial blood samples do provide an exact gas status, which may be necessary for the optimum patient surveillance [96,97].



### Pulse oximetry

Pulse oximetry allows monitoring of systemic oxygenation. The technique is widespread and easy to use. Motion like tremors may interrupt the $SpO_2$ signal and the measuring site should be without sores, breaks and birthmarks. Finger or toe measurements in patients with poor peripheral circulation may also be problematic. Skin pigmentation and nail polisher may give bias. Most oximeters are accurate within the range of ±3-5 %, and are considered to be unreliable at levels below 70 %. Due to the flat shape of the oxygen dissociation curve at high oxygen levels, it is not possible to estimate

$PaO_2$ to detect hyperoxia. The staff should be aware that $SpO_2$ readings might not be accurate due to elevated levels of carboxyhemoglobin, changes in pH, temperature, 2,3-DPG and $pCO_2$ levels or abnormal hemoglobin levels. If these factors are taken into consideration, the technique is valuable, cheap and easy to use. However, $SpO_2$ only shows the oxygenation level and not the carbon dioxide level. Weaning from mechanical ventilation, tidal volume reduction in patients with acute respiratory distress syndrome and management of patients with brain edema require carbon dioxide tension monitoring [98,9,40,19,21].

### Gastric tonometry and sublingual capnometry

Gastric tonometry and sublingual capnometry are based on the principle that tissue carbon dioxide is elevated in patients with poor perfusion. The gastric tonometry technique requires an insertion of the specialized nasogastric tube. The method is described as difficult and therefore not often used, e.g. it requires long equilibration time (ideally 90 minutes if the tube balloon is fluid-dependent, and nearly 20 minutes for the gas-dependent type). Histamine type 2 blockers are routinely required to limit the intraluminal generation of carbon dioxide from the gastric acid and enteral nutrition has to stop 2 hours prior to each measurement. The sublingual $pCO_2$ monitoring has been used in conditions in which the gastrointestinal system has been deprived of adequate perfusion, e.g. early stages of shock. It is "non-invasive" and provides near-instantaneous information. However, there is limited clinical experience with this technique. So far both methods show close relation to decreases in arterial pressure and cardiac index during circulatory or septic shock. They only provide intermittent measurements and they need a nurse to use a probe to acquire each data point. Due to the limited use these techniques will not be discussed any further [4, 64, 99].

### End-tidal $pCO_2$

End-tidal $pCO_2$ monitoring refers to non-invasive measurement of exhaled carbon dioxide concentrations at end-expiration. It is used mainly to verify the endotracheal tube (ETT) position and during cardio-pulmonary resuscitation (CPR). It has become standard of care in the operating room, in some ICUs and is now being increasingly used in the emergency department. The significant inaccuracy introduced into end-tidal $pCO_2$ monitoring by the presence of intrapulmonary shunting and dead space ventilation is a problem with the technique. This inaccuracy is also found in patients with intrinsic lung disease, ventilation/perfusion mismatch or in patients with small tidal volumes (e.g. neonates and infants). Studies have shown that in all these patients end-tidal $pCO_2$ is less accurate than tc$pCO_2$. Several studies have shown that while end-tidal $pCO_2$ significantly increases during one-lung ventilation, neither tc$pCO_2$ nor $PaCO_2$ show the same changes [21,27,36,46,68,69,100,101].



While both end-tidal and TC measurements are most frequently used instead of $PaCO_2$, they indirectly monitor different elements of carbon dioxide production, transport and elimination. In a comparison study the authors conclude that end-tidal $pCO_2$ values may not always accurately reflect $PaCO_2$; however, end-tidal $pCO_2$ measurement still provides information that can be derived from the carbon dioxide waveform and it has a rapid response time [21,102].

### tc$pCO_2$

tc$pCO_2$ monitoring (and for neonates also tc$pO_2$ monitoring) provides nearly instant and continuous information on the body's peripheral circulation and ability to remove carbon dioxide via the cardiopulmonary system (and deliver oxygen to the tissue). The technique accurately estimates $PaCO_2$ in

case of significant cardio-respiratory dysfunction. The monitor can be moved around together with the patient. However, the sensor requires heating and regular calibration, the measuring site should frequently be changed and the sensor must regularly be remembraned. On the other hand TC is non-invasive, easy to use, needs short calibration time and does not involve intubation. Measurements of transcutaneous carbon dioxide during HFJV/HFOV are recommended by manufacturers of these techniques. And tc$pCO_2$ trending can validate or limit the need for more costly and higher risk monitoring technology such as arterial blood samples [4,21,102].


Summary

All techniques have specific advantages and disadvantages. In some patients the non-invasive transcutaneous technique is the most simple and the best choice. It offers relevant and continues non-invasive monitoring of patients with cardio-respiratory disease (of any age). In other segments the best way to monitor can be obtained by combining one or more techniques (TC, ABG, $SpO_2$ or end-tidal $pCO_2$). For example when transcutaneous carbon dioxide monitoring combined with pulse oximetry enhance intermittent invasive arterial blood gas samples. All in all, these four techniques complement rather than exclude each other in reaching the important goal of: Optimizing patient's ventilatory and respiratory status.

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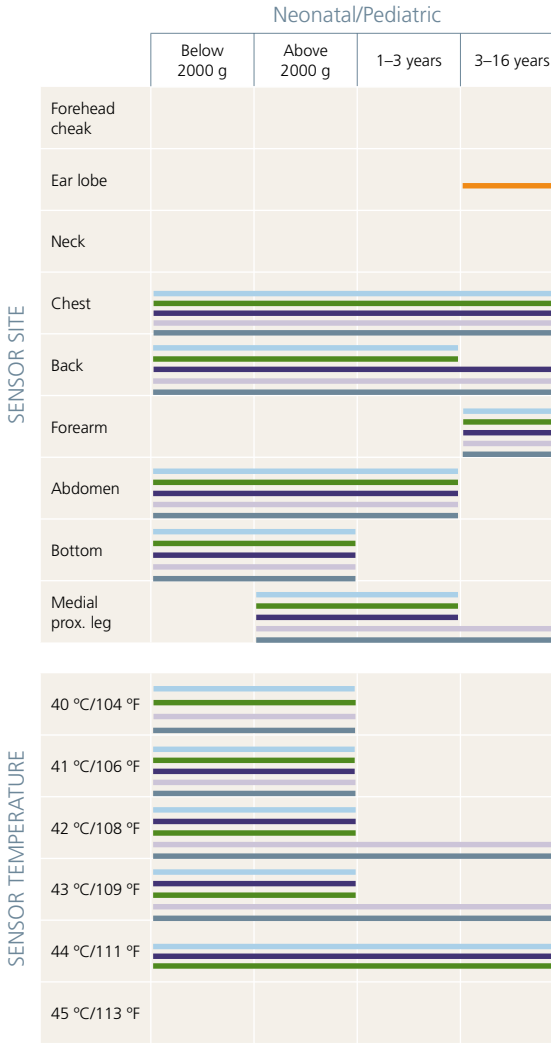
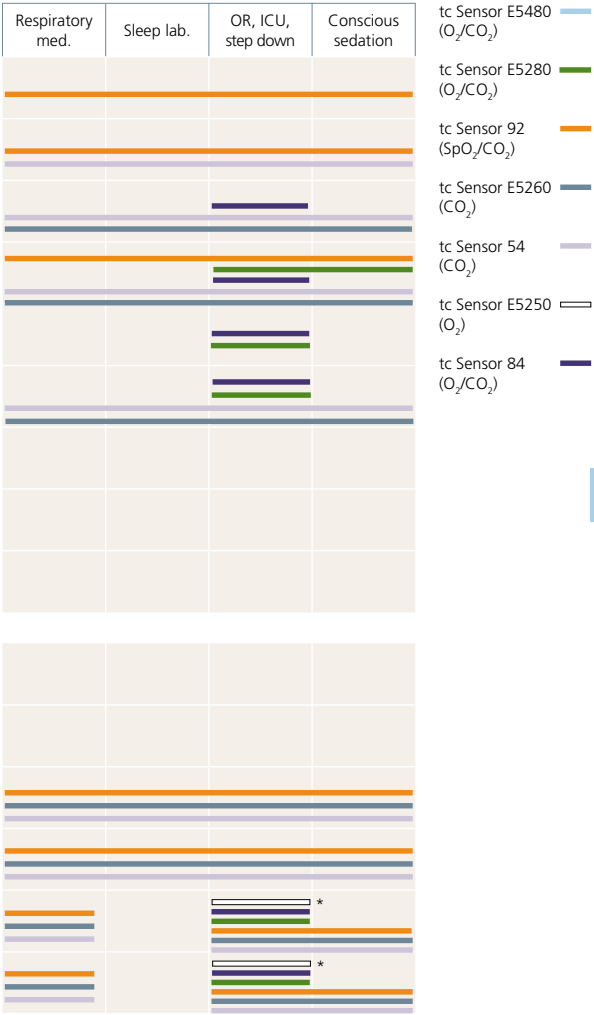
## Choice of sensor site and temperature




The diagram is based on market experience and should not be used as general rule

Adult




*Shock warning

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